Pacific Island Network
Vital Signs Monitoring Plan:
Phase III Report

Appendix E: Topical Working Group Report – Geology

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Pacific Island Network (PACN)

Territory of Guam
War in the Pacific National Historical Park (WAPA)

Commonwealth of the Northern Mariana Islands
American Memorial Park, Saipan (AMME)

Territory of American Samoa
National Park of American Samoa (NPSA)

State of Hawaii
USS Arizona Memorial, Oahu (USAR)
Kalaupapa National Historical Park, Molokai (KALA)
Haleakala National Park, Maui (HALE)
Ala Kahakai National Historic Trail, Hawaii (ALKA)
Puukohola Heiau National Historic Site, Hawaii (PUHE)
Kaloko-Honokohau National Historical Park, Hawaii (KAHO)
Puuhonua o Honaunau National Historical Park, Hawaii (PUHO)
Hawaii Volcanoes National Park, Hawaii (HAVO)

http://science.nature.nps.gov/im/units/pacn/monitoring/plan/

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EXECUTIVE SUMMARY

Geology is a major determinant of the topography, water and soil chemistry, soil fertility, hillside stability, and surface and groundwater flow within the National Parks. This report addresses the geologic processes at work in the Pacific Island Network (PACN), the importance of those processes to the ecosystem, and the influence of humans on those processes. The geologic resources of a park – rocks, soils, caves, fossils, stream networks, springs, volcanoes, beaches, etc. – provide the precise set of physical conditions required to sustain the biological system. Interference with geologic processes and alteration of geologic features may affect habitat conditions. Alternatively, a manipulation of the biological system can trigger changes in the geologic system. Geological processes that directly affect biological processes include stream and groundwater flow, erosion and deposition, weathering and mass wasting (landslides and rockfalls), earthquakes, and volcanic phenomena (eruptions and hot springs). These processes collectively operate on a variety of time scales, though it is possible for all of them to be operating at once in a single park.

The geologic histories of the Pacific Island Network National Park Service areas are geographically distinct, though some similarities exist. The Hawaiian Islands are located at the southeastern end of a chain of shield volcanoes that began to form more than 70 million years ago, and owe their existence to a "hot spot" in the Earth's mantle that has changed location only slightly during this time. Each Hawaiian island is made of one or more volcanoes, which first erupted on the sea floor and only emerged above the ocean's surface after many eruptions. On Hawaii Island, Kilauea, Mauna Loa, and Hualalai have erupted in the past 200 years and are therefore considered active (Parks: ALKA, HAVO, PUHO, KAHO, PUHE). East Maui Volcano, commonly known as Haleakala last erupted 400-500 years ago (Parks: HALE). Molokai is composed of three different extinct volcanoes, Kamakou (East Molokai), Maunaloa (West Molokai) and Puu Uao (the Kalaupapa peninsula), which last erupted 230,000 years ago (Parks: KALA). Oahu is composed of two volcanoes, Koolau (east) and Waianae (west), which last exhibited volcanism 22,000 years ago (Parks: USAR).

Guam and Saipan are part of the Mariana Islands, a curved line of stratovolcanoes that rise from the ocean floor. The islands owe their origin to subduction, the tectonic process that thrusts one plate beneath another. The union of two volcanoes formed Guam although much of the island is characterized by limestone karst topography exposed due to uplift associated with the subduction of the Pacific plate (Parks: WAPA). Saipan is similar to Guam, and is mainly composed of limestone resting on a volcanic core (Parks: AMME). Active volcanism in the Marianas is concentrated on the islands north of Saipan.

American Samoa is a collection of five volcanic islands and two coral atolls (Parks: NPSA). Rugged peaks and narrow coastal plains characterize Tutuila, Ofu, and Olosega, whereas Tau is a shield volcano, and Aunuu is a tuff cone with a substantial coastal plain. These shield volcanoes were formed by a stationary hot spot as the Pacific Plate slid west, similarly to the Hawaiian Islands. The youngest islands are in the eastern part of the chain. The most recent eruption on the main islands occurred in 1866 along the submarine ridge connecting Olosega with Tau Island.

Geologic maps of the subaerial (submerged) portion of the islands exist for all of the Pacific Island National Parks. Geology monitoring programs are being conducted in many of the parks.

The most extensive of these is through the USGS, which operates the Hawaiian Volcano Observatory (HVO) in HAVO. In addition, the USGS Water Resources Division (WRD) has activities in many of the parks. The USGS Coastal and Marine Geology Program has conducted offshore mapping in Hawaii, Maui, Molokai, and Oahu (Parks: PUHO, PUHE, KAHO). The EPA and some universities also have monitoring programs.

Geologic concerns vary among PACN parks. On Hawaii Island, Hawaii Volcanoes NP (HAVO) is located on Kilauea and Mauna Loa, two of the most active volcanoes in the world. Volcanic issues of concern for HAVO include eruption of lava, pyroclastic materials, vog (volcanic haze), and subsurface thermal heating. In addition, earthquakes and tsunami are major threats to the park. Mass wasting, coastal erosion, lava tubes and groundwater flow to anchialine pools are other geological features important to the park. Kaloko-Honokohau NHP (KAHO) is situated on Hualalai, which last erupted in 1801 and is considered active. KAHO is also exposed to poor air quality from vog generated by Kilauea. Other processes of concern include relative sea level rise, tsunami, and continuing development adjacent to the park, which affects marine sedimentation, coastal erosion, and groundwater withdrawal and contamination. At Puukohola Heiau NHS (PUHE), erosion due to development upslope is a major concern, as are relative sea level rise, tsunami, groundwater withdrawal and contamination, and coastal erosion. Puuhonua o Honaunau NHP (PUHO) is located on Mauna Loa, which last erupted in 1984, and is considered active. Other issues of concern for the park include vog, tsunami, relative sea level rise, coastal erosion, and nearby development and its effects on groundwater withdrawal and contamination. The Ala Kahakai NHT (ALKA) traverses a large fraction of coastal Hawaii, and thus encounters all of the geological processes that affect HAVO, PUHO, KAHO and PUHE. Mass wasting, coastal erosion, groundwater withdrawal and contamination, earthquakes, tsunami and lava flows are some of the most important processes affecting the trail.

Haleakala NP (HALE) rests on East Maui Volcano, which was last active 300-400 years ago. Therefore, a volcanic hazard and the potential for volcanic-related seismicity exist. HVO has a limited monitoring program for ground deformation and seismicity. Other geological processes of concern include wind and water erosion, mass wasting, vog, tsunami, and coastal erosion. On Molokai, Kalaupapa NHP (KALA) is situated on Kamakou and Puu Uao volcanoes, which last erupted about 1.5 million years ago and 230,000 years ago respectively. Groundwater withdrawal, stream diversion, sedimentation, tsunami, and mass wasting are the geologic processes of major concern. On Oahu, the primary resource of the USS Arizona Memorial (USAR) is the sunken ship. Geologic processes that could affect the ship include earthquakes, tsunami, and relative sea level rise (though Pearl Harbor is well protected from both ocean waves and tsunami due to the shape and location of the harbor entrance and its proximity to the opening in the channel reef).

The National Park of American Samoa (NPSA) consists of three units on separate islands. Sedimentation, soil erosion, mass wasting, coastal erosion, surface water diversion and groundwater withdrawal, tsunami, and relative sea level rise are important geological processes affecting the park. Volcanic activity is also a concern; eruptions have occurred in historic times along the ridge connecting Olosega with Tau Island, as well as at Vailuluu, the seamount east of Tau.

On Guam, the War in the Pacific NHP (WAPA) has a several significant concerns, including coastline modification, coastal and terrestrial erosion and sedimentation, relative sea level rise, adjacent development, groundwater withdrawal and contamination, tsunami, and potential mass wasting. On Saipan, American Memorial Park (AMME) has several significant concerns, including coastal and terrestrial erosion, wetland loss, groundwater withdrawal and contamination, adjacent land development, and contaminated surface runoff.

INTRODUCTION

SCOPE OF TOPIC AREA

The Pacific Island Network (PACN) Geology topical workgroup is focused on the abiotic components of the ecosystem, particularly geology but also including hydrology (other physical parts of the ecosystem include meteorology, discussed by the Air Quality & Climate topical workgroup, marine processes, discussed by the Marine topical workgroup, and water quality, discussed by the Water Quality topical workgroup). Physical components of ecosystems can be bellwethers of significant ecosystem change, and monitoring these components provides important information on the complex interactions that take place with the ecosystem. Topics discussed by this report include volcanic activity, earthquakes, hydrology, coastal processes, soil condition, erosion and landslides.

BACKGROUND

The Territory of American Samoa, the Mariana island arc (including Guam and Saipan), and Hawaiian Islands have different geologic histories and are treated as independent regions in this report. The Territory of Guam and Commonwealth of the Northern Mariana Islands (CNMI) are part of the Mariana island arc; for this reason, they are treated together in this discussion though they are politically distinct.

MONITORING GOALS AND OBJECTIVES

The principle objective of the geology topical workgroup is to summarize existing data and help develop a geologic monitoring program. Geologic monitoring can be used to detect long term environmental change, provide insights into the ecological consequences of those changes, and help determine if the observed changes should mandate a corrective action in management practices. The concept of "Geoindicators" as developed by the International Union of Geological Sciences through its Commission on Geological Sciences for Environmental Planning is being used in environmental and ecological monitoring, state-of-the-environment reporting, and general assessments of environmental sustainability on local, national, and international scales. The PACN is using Geoindicators in the development of its monitoring program to detect environmental changes to geologic resources and to assess whether the changes are within a normal or anticipated range of variation. Geologic indicators include measurements of change in volcano activity, earth movement, shoreline movement, sand dune movement or mobilization, sediment storage and loading, soil erosion, and slope and rock stability.

LEGISLATION AND POLICY

As a federal agency, the NPS operates under a hierarchy of legislative mandates, including federal laws, executive orders, Department of the Interior and NPS policies and directives, as well as county, state, commonwealth, and territorial regulations. Further, management of submerged resources is complicated by jurisdictional or administrative issues that are often managerially more challenging than similar issues on land. These complexities require the NPS to cooperate with numerous and often overlapping federal and local agencies to achieve its objectives.

I & M - Natural Resource Challenge

The Natural Resource Challenge (NRC), initiated in 1999, is an action plan for preserving natural resources through the National Park Service (NPS). The NRC assisted NPS to establish 32 Inventory and Monitoring networks, which includes 270 National Parks. In the Networks, parks are grouped that share geographical and natural resource characteristics. The Inventory and Monitoring (I&M) Program is designed to first complete basic inventories of natural resources in parks, on which to base long-term monitoring efforts. Monitoring programs are based on monitoring critical parameters (Vital Signs) within each network to incorporate into natural resource management and decision-making. “Vital Signs are measurable, early warning signals that indicate changes that could impair the long-term health of natural systems” (NPS, 2003).

Federal Policy

Federal Legislation

- NPS Organic Act (1916)- Established the National Park System "…to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such a manner and by such means as will leave them unimpaired for the enjoyment of future generations." While long considered a dual mission, court decisions (e.g., Southern Utah Wilderness Alliance vs. Dabney) support only a single mission: conservation (=preservation) of natural and cultural resources. According to the courts, without conservation of these irreplaceable resources, the perceived second mission could not be accomplished.
- Watershed Protection and Flood Prevention Act (1954)- This act authorizes the Secretary of the Interior to cooperate with state and local governments, including soil and water conservation districts and flood control districts, in planning and analyzing trends in flood protection and watershed conservation activities and facilities. The Secretary is to be consulted about such proposed "works of improvement," with regard to activities or facilities that may affect DOI lands.
- National Environmental Policy Act (1969)-The National Environmental Policy Act (NEPA) forms the framework of modern environmental policy for all federal projects, agencies and employees and mandated that all federal actions take into account the effects of the proposed activity on the environment. NEPA also provides for public input into the federal process.
- Wilderness Act (1969)- The "Wilderness" Act defined: “A wilderness, in contrast with those areas where man and his own works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man

himself is a visitor who does not remain. An area of wilderness is further defined to mean in this chapter an area of underdeveloped Federal land retaining its primeval character and influence, without permanent improvements or human habitation, which is protected and managed so as to preserve its natural conditions and which (1) generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable; (2) has outstanding opportunities for solitude or a primitive and unconfined type of recreation; (3) has at least five thousand acres of land or is of sufficient size as to make practicable its preservation and use in an unimpaired condition; and (4) may also contain ecological*, geological, or other features of scientific,* educational, scenic, or historical value."

- Geothermal Steam Act (1970)- This act prohibits leasing of federally owned geothermal resources in all units of the National Park System, including the three units specifically open to mineral leases. The Geothermal Steam Act Amendments of 1988 provide added protection for selected parks by requiring BLM to obtain NPS consent before issuing a geothermal lease on lands adjacent to listed park units. The regulations at 43 CFR 3200 govern geothermal leasing on lands adjacent to park units.
- Coastal Zone Management Act (1972)- Established a voluntary national program within the Department of Commerce to encourage coastal States and territories to develop and implement coastal zone management plans that would define the boundaries of the coastal zone, identify uses of the area to be regulated by the State, the mechanism for controlling such uses, and broad guidelines for priorities of uses within the coastal zone.
- Federal Water Pollution Control Act (1972)- This legislation, more commonly known as the Clean Water Act, is aimed at restoring and maintaining the chemical, physical and biological integrity of the nation's waters. This Act authorized the EPA to prepare comprehensive programs for eliminating or reducing the pollution of interstate waters and tributaries and improving the sanitary condition of surface and underground waters. Due regard was to be given to improvements necessary to conserve waters for public water supplies, propagation of fish and aquatic life, recreational purposes, and agricultural and industrial uses. A number of other provisions found in the current Act were adopted prior to 1972.
- Mining in the Parks Act (1976)- Sec. 1901 states that "the level of technology of mineral exploration and development has changed radically in recent years and continued application of the mining laws of the United States to those areas of the National Park System to which it applies, conflicts with the purposes for which they were established; and all mining operations in areas of the National Park System should be conducted so as to prevent or minimize damage to the environment and other resource values, and, in certain areas of the National Park System, surface disturbance from mineral development should be temporarily halted while Congress determines whether or not to acquire any valid mineral rights which may exist in such areas."
- NPS Omnibus Act Management Act (1998)- Commonly called the "Thomas Bill", the National Parks Omnibus and Management Act (NPOMA) clarified the role of the National Park Service as a conservation and science agency. Among the items it specifically mandated were establishment of an inventory and monitoring program to obtain baseline information, development of a broad, rigorous scientific research

program, and hiring and training of scientists within the NPS. Additionally, NPOMA granted protection for key natural resources, particularly geological/paleontological resources within the park by restricting sensitive information from release under the Freedom of Information Act.

- Federal Cave Resources Protection Act (1998)-Sec. 4301 states, "Significant caves on Federal lands are an invaluable and irreplaceable part of the Nation's natural heritage; and in some instances, these significant caves are threatened due to improper use, increased recreational demand, urban spread, and a lack of specific statutory protection. The purposes of this chapter are - to secure, protect, and preserve significant caves on Federal lands for the perpetual use, enjoyment, and benefit of all people; and to foster increased cooperation and exchange of information between governmental authorities and those who utilize caves located on Federal lands for scientific, education, or recreational purposes. It is the policy of the United States that Federal lands be managed in a manner which protects and maintains, to the extent practical, significant caves."

Executive Orders

- Executive Order 11988 (Floodplain Management; 1977)- "Each agency shall provide leadership and shall take action to reduce the risk of flood loss, to minimize the impact of floods on human safety, health and welfare, and to restore and preserve the natural and beneficial values served by floodplains in carrying out its responsibilities for (1) acquiring, managing, and disposing of Federal lands and facilities; (2) providing Federally undertaken, financed, or assisted construction and improvements; and (3) conducting Federal activities and programs affecting land use, including but not limited to water and related land resources planning, regulating, and licensing activities."
- Executive Order 11990 (Protection of Wetlands; 1977)-"Each agency shall provide leadership and shall take action to minimize the destruction, loss or degradation of wetlands, and to preserve and enhance the natural and beneficial values of wetlands in carrying out the agency's responsibilities for (1) acquiring, managing, and disposing of Federal lands and facilities; and (2) providing Federally undertaken, financed, or assisted construction and improvements; and (3) conducting Federal activities and programs affecting land use, including but not limited to water and related land resources planning, regulating, and licensing activities."

NPS MANAGEMENT POLICY

Park Enabling Legislation

- Ala Kahakai National Historic Trail (ALKA) enabling legislation: **"…**the trail…contains a variety of significant cultural and natural resources."
- Haleakala National Park (HALE) enabling legislation: "That the Secretary of the Interior shall make and publish such general rules and regulations as he may deem necessary and proper for the management and care of the park and for the protection of the property therein, especially for the preservation from injury or spoliation of all timber, natural curiosities, or wonderful objects within said park."

- Hawaii Volcanoes National Park (HAVO) enabling legislation: "That the Secretary of the Interior shall make and publish such general rules and regulations as he may deem necessary and proper for the management and care of the park and for the protection of the property therein, especially for the preservation from injury or spoliation of all timber, natural curiosities, or wonderful objects within said park."
- Kalaupapa National Historical Park (KALA) enabling legislation: "…to research, preserve, and maintain...natural features…" 16 U.S.C. § 410jj.
- Kaloko-Honokohau National Historical Park KAHO enabling legislation: "Sec. 505 (d)(4) – Secretary shall consult with and may enter into agreements with other government entities and private landowners to establish adequate controls on air and water quality and the scenic and esthetic values of the surrounding land and water areas. In consulting with and entering into any such agreements, the secretary shall to the maximum extent feasible utilize the traditional native Ahupuaa concept of land and water management."
- War in the Pacific National Historic Park (WAPA) enabling legislation: "…To conserve and interpret outstanding natural, scenic, and historic values and objects on the island of Guam for the benefit and enjoyment of present and future generations, the War in the Pacific National Historical Park is hereby established."

Management Policies

- NPS Management Policies (2001): Natural Resource Management Reference Manual 77 (RM#77)[1]- This document is the Service's comprehensive guideline on natural resource management. Its purpose is to guide the actions of park managers so that natural resource management activities planned and initiated at field areas comply with federal law and regulation and Department of the Interior and NPS policy. Relevant sections include Freshwater Resources Management, Marine Resources Management, Geologic Resources Management, Soil Resources Management, Cave Management, and Paleontological Resources Management. For instance, Section 4.8 states, "the Park Service will preserve and protect geologic resources as integral components of park natural systems. As used here, the term "geologic resources" includes both geologic features and geologic processes. The Service will (1) assess the impacts of natural processes and human-related events on geologic resources, (2) maintain and restore the integrity of existing geologic resources, (3) integrate geologic resource management into Service operations and planning, and (4) interpret geologic resources for park visitors."
- Natural Resources Inventory and Monitoring Guideline, NPS-75[2]- The Servicewide Inventory and Monitoring Program will chart the course and provide the leadership and information resources needed by the National Park Service to preserve and protect the natural resources placed under its trust by the American people into the 21st Century and beyond. There is a chapter specifically dealing with Chemical and Geophysical resources inventory and monitoring.

[1] http://www.nature.nps.gov/RM77/
[2] http://www.nature.nps.gov/im/monitor/nps75.pdf

REGIONAL POLICY

Agencies responsible for various aspects of local policy relating to geology in the PACN are listed below. Mandates and funding for these agencies vary.

- In Hawaii:
  - State Civil Defense- Manages the impacts of geologic hazards such as lava flows and tsunami.
  - Department of Land and Natural Resources (DLNR)- Is responsible for managing over half of Hawaii's land, including the 11th largest state forest, the nation's largest tropical rainforest, and the fourth longest coastline in the United States. Offices include: Aquatic Resources, Boating and Ocean Recreation, Conservation and Resources Enforcement, Bureau of Conveyances, Forestry and Wildlife, Historic Preservation, Land Management, State Parks, and Water Resource Management. With respect to geology, DLNR are the stewards of state lands, making them responsible for site preservation and hazards mitigation plans written by other state agencies.
  - Hawaii Commission on Water Resource Management – Part of the DLNR, the Commission on Water Resource Management administers the State Water Code, which was created by the 1987 Hawaii State Legislature. The Commission's general mission is to protect and enhance the water resources of the State of Hawaii through wise and responsible management.
- In the CNMI: The Emergency Management Office's role is to develop and maintain a comprehensive program of emergency management activities that supplement, facilitate and provide leadership to government and private organizations before, during, and after emergencies and/or disasters, including but not limited to earthquakes, tsunami, and volcanic eruptions.
- In American Samoa: the Territorial Emergency Management Coordinating Office has the primary mission to protect the lives and property of the Territory's people from the adverse effects of natural and manmade disasters.

ECOLOGICAL CONTEXT

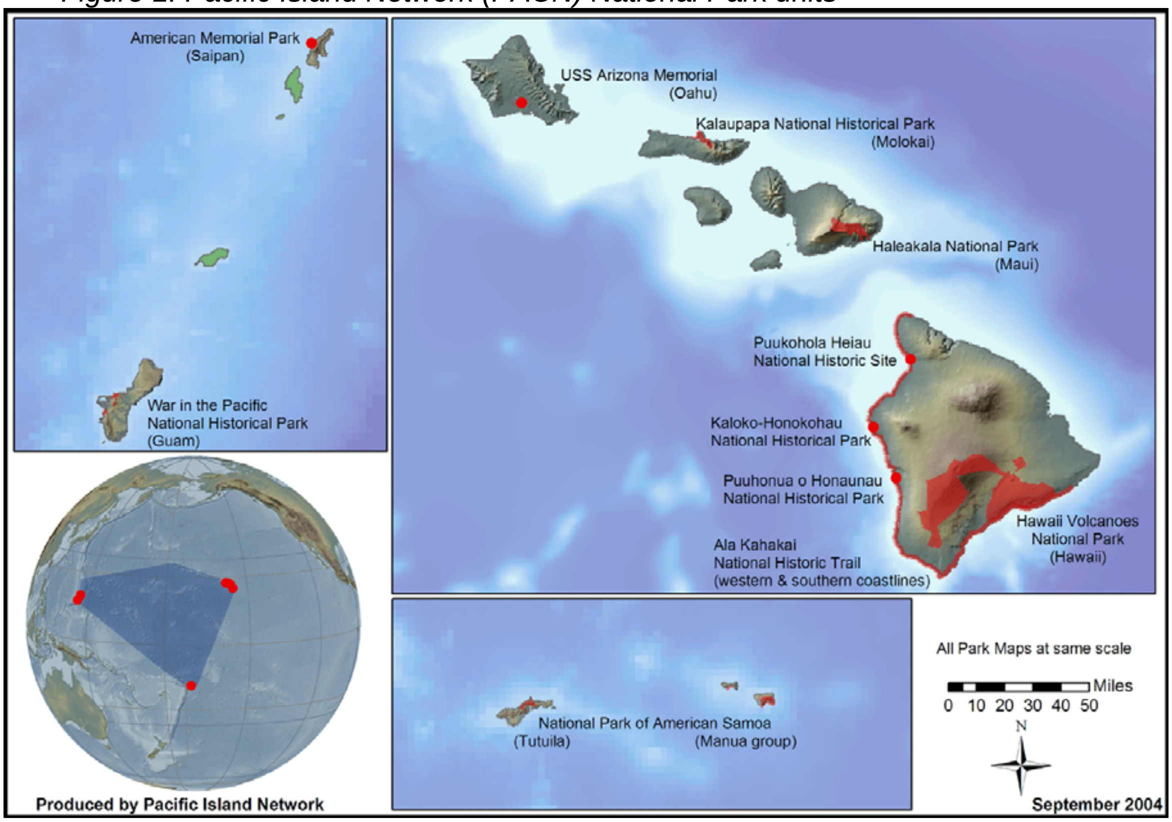
GEOGRAPHY

The Hawaiian Islands (Figure 1) are alpine to sub-tropical, marine (northeast trade-wind) influenced islands. A chain of 132 islands spread over 1,523 miles (2,451 km) make up the state we call Hawaii, though we generally only think of the eight main islands. The highest point is the volcano, Mauna Kea, at 13,796 feet (4,205m) in elevation.

Guam and Saipan are tropical, marine (northeast trade-wind) influenced islands. They are part of the Mariana Islands island arc that extends about 560 miles (900 km) north-south along the edge of the Mariana Trench in western Micronesia. The highest elevation on Guam is 600 feet (183m) at Ritidian Point on the northwest tip of the island, and this height slips gradually down to the southwest until it reaches approximately 200 feet (61m) above sea level at Guam's center. Guam is shaped like a footprint being 30 miles (48 km) long while the width is narrowest (4 miles (6 km) across) at its waist and widest (nearly 12 miles (19 km)) in the south. Saipan is about 12.5 miles (20 km) long and 5.5 miles (9 km) wide. Mt. Tapotchau, at 1,554 feet (471m), is the highest point.

American Samoa is a group of tropical, marine (southeast trade-wind) influenced islands. Tutuila is about 18 miles (29 km) long by 5 or 6 miles (8-10 km) wide. A mountainous ridge extends nearly the length of the island, with spurs on both sides. The highest elevation, Matafao Peak, is 2,142 feet (652 m). Between 60 and 70 miles (97-113 km) eastward of Tutuila are three small islands, together called the Manua Group. The largest is Tau, whose greatest elevation is 3,160 feet (963 m). The other two islands, Ofu and Olosega are separated by shallow water. The elevation of Ofu is given as 1,587 feet (484m), of Olosega 2,095 feet (630m). Rose Atoll lies 78 nautical miles (144km) eastward from Tau.

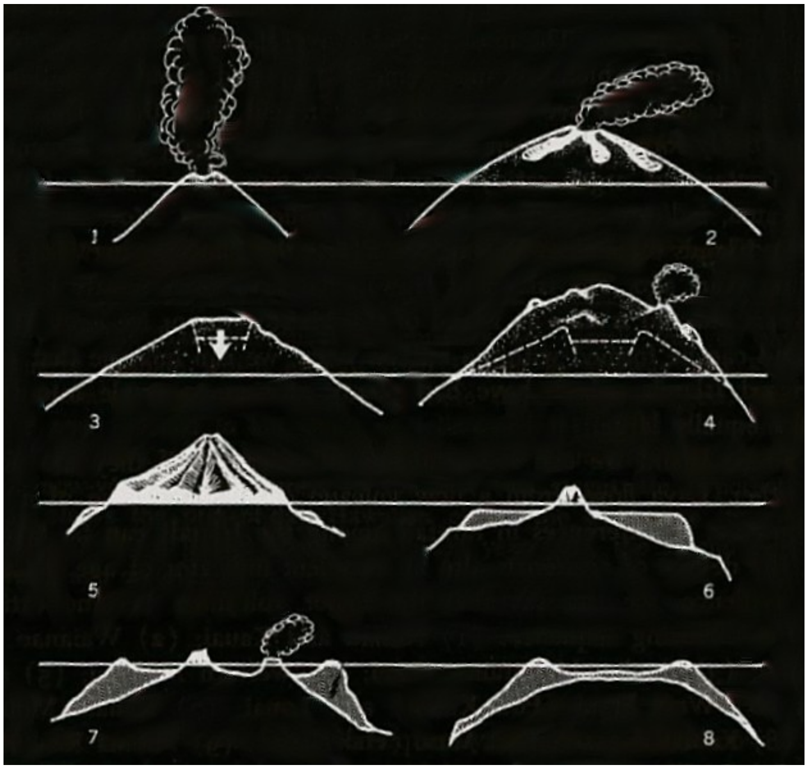
Figure 1. Pacific Island Network (PACN) National Park units



GEOLOGY

The Hawaiian Islands are at the southeastern end of a chain of shield volcanoes that began to form more than 70 million years ago (Figure 2). Many of these volcanoes formed islands that have subsided, continued to erode, and are once again beneath sea level. Some of the old volcanoes probably never reached sea level. Each Hawaiian island is made of one or more volcanoes, which first erupted on the sea floor and only emerged above the ocean's surface after multiple eruptions. Figure 2 illustrates the typical stages of formation and evolution of a volcanic island: 1) submarine eruptive phase, 2) aerial crater formation, 3) caldera formation as summit sinks, 4) buildup of lavas over the caldera and cinder cone formation, 5) erosion, marine cliff formation, and fringing coral reef construction, 6) erosion of surface land and conversion of fringing reef to barrier reef, 7) origin of lateral cone by submarine activity, and 8) submersion of island and expansion of barrier reef.

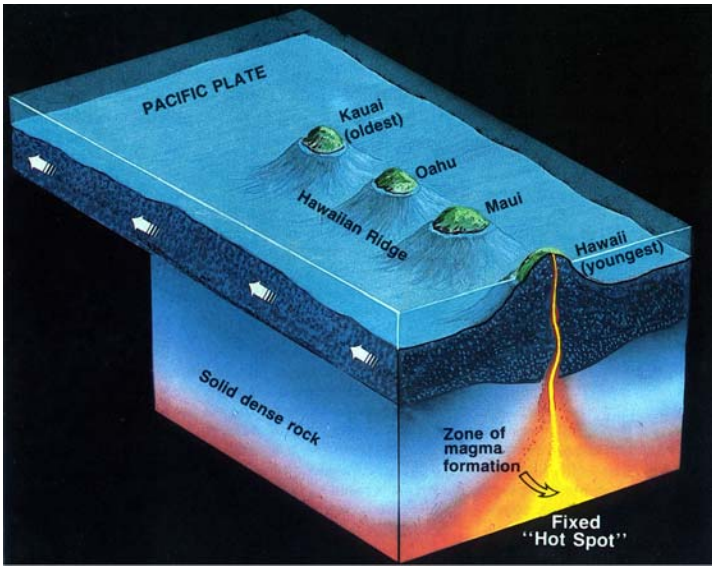
Figure 2. Stages of volcanic island formation and evolution (modified from Carlquist, 1980). See text for details.



The largest and most southeastern island of the chain, Hawaii, consists of five volcanoes. Kilauea, Mauna Loa, and Hualalai have erupted in the past 200 years and are therefore considered active (Parks: ALKA, HAVO, PUHO, KAHO, PUHE), while Kohala and Mauna Kea are considered dormant (Parks: ALKA, PUHE). East Maui Volcano, commonly known as Haleakala last erupted 400-500 years ago (Parks: HALE). Molokai is composed of three different extinct volcanoes, Kamakou (East Molokai), Maunaloa (West Molokai) and Puu Uao (the Kalaupapa peninsula), which last erupted 230,000 years ago (Parks: KALA). Oahu is composed of two volcanoes, Koolau (east) and Waianae (west), which exhibited renewed volcanism 22,000 years ago (Parks: USAR).

The Hawaiian Islands owe their existence to a "hot spot" in the Earth's mantle that has changed location only slightly over the past 70 million years. The hot spot is currently located beneath the southeastern part of Hawaii Island (Figure 3). Countless eruptions of lava fed by the hot spot built volcanoes on the Pacific Plate. Eventually these volcanoes grew above sea level to form islands. Volcanoes did not continue to erupt, because the Pacific Plate is continually moving northwestward across the hot spot at a rate of 7-9 cm per year. Eventually each volcano was torn away from the hot spot and carried northwestward, just as a conveyor belt moves material from one location to another.

Figure 3. Hawaiian Hotspot (modified from a drawing by M. Krafft, Centre de Volcanologie, France)

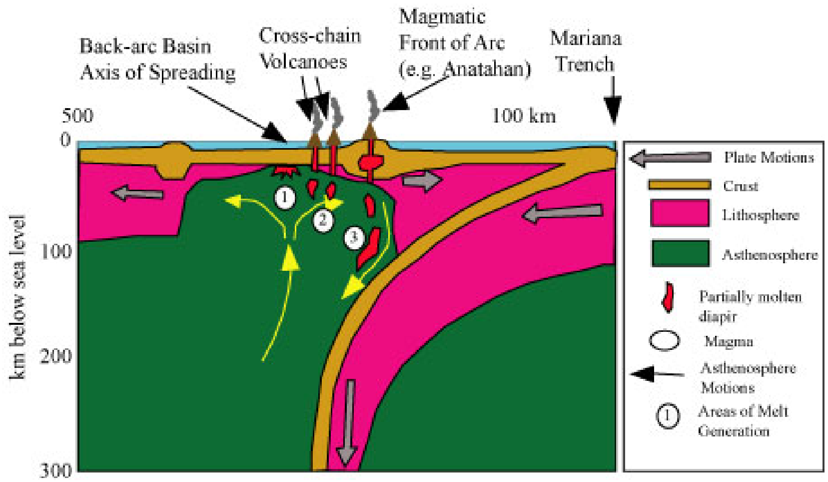


Guam and Saipan are part of the Mariana Islands, a classic example of an island arc – a curved line of stratovolcanoes that rise up from the ocean floor. The islands owe their origin to subduction, the tectonic process that thrusts one plate beneath another (Figure 4). The Pacific Plate subducts underneath the Philippine Plate and magma rises up from the aesthenosphere to form the volcanoes that compose the islands. Volcanic activity that initiated the growth of the islands occurred between 45 million years ago and 10 million years ago.

The union of two volcanoes formed Guam, although much of the island is characterized by karst topography (Parks: WAPA). Surrounded by coral reefs, the island has two basic geological compositions: in the central and northern portion is a relatively flat, raised coralline limestone plateau, sections of which are steep coastal cliffs. The southern portion is a mix of high volcanic hills and valleys composed of pillow basalts, basalt flows and volcanic derived sedimentary rocks interfingered with limestone. The limestone is exposed on the islands due to uplift associated with the subduction of the Pacific plate.

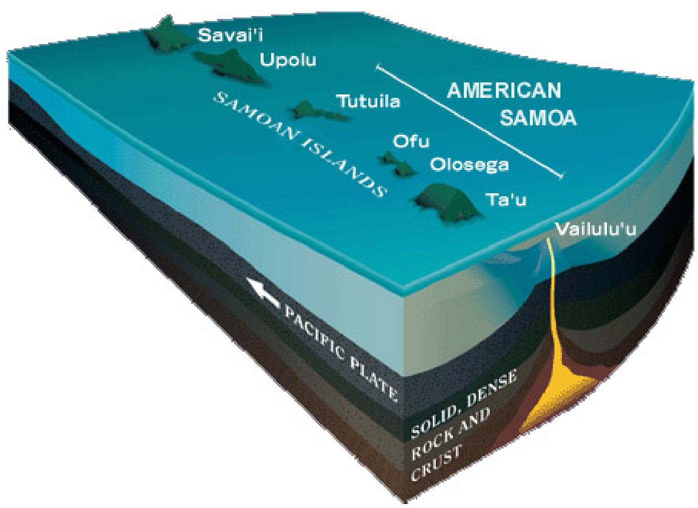
Saipan is similar to Guam in that it is mainly composed of limestone resting on a volcanic core. It has a central highland of volcanic and volcanic-derived sedimentary rocks interfingering with limestone of Late Eocene to Pleistocene age (Parks: AMME).

Figure 4. The Mariana subduction zone is an outstanding example of an island arc associated with back-arc spreading (modified from Stern et al., 2001)



American Samoa is a collection of volcanic islands with rugged peaks and limited coastal plains plus two coral atolls. These shield volcanoes formed on top of a stationary hot spot as the Pacific Plate slid west (Figure 5), similarly to the Hawaiian Islands. The youngest islands are in the eastern part of the chain. Vailuluu, a submarine volcano, marks the current location of the hotspot.

Figure 5. Samoan hotspot (modified from L. Lippsett, Currents, 2001: Drawing by J. Doucette.)



CONCEPTUAL ECOLOGICAL MODEL

GEOLOGIC STRESSORS

In section 4, local and park issues are broken down in the format of our conceptual model based on geography. The main geologic stressors/resources for PACN parks are erosion/mass wasting, hydrology, littoral/marine, seismicity, soil and volcanic activity. Stressors are major agents of change that affect park ecosystems. These broad areas can be broken down further as detailed in the conceptual model (Appendix B).

MEASURABLE ATTRIBUTES

Geologic indicators (Appendix C) are one framework currently being used to monitor geologic resources. They are earth system processes and phenomena that are liable to change in less than a century in magnitude, direction, or rate to an extent that may be significant for environmental sustainability and ecological health. Baseline measurements for those geoindicators deemed important to the various national parks in the Pacific Island Network need to be established (one size does not fit all Parks, not all of the listed geoindicators need be monitored in a given park). Geoindicators have been developed as tools to assist in an integrated assessment of natural ecosystems.

PARK AND NETWORK WIDE ISSUES

The purpose of this section is to describe the important geologic processes and focal resources which may act as stressors on each park's ecosystems. These important geological resources and processes are outlined in Table 1.

Table 1. Natural ecosystem drivers/focal resources in PACN Parks (Geology)

	Volcanic Unrest				Seismicity	Slope Failure (mass wasting)	Erosion (water, wind)	Hydrology			Soil	Littoral & Marine	
	Lava flows	Tephra	Air Quality	Lava tubes & caves				Ground water	Surface water	Karst		Sea Level Rise	Coastal erosion
ALKA - Ala Kahakai Trail	P		P	P	P	P	P	P	P		P	P	P
AMME - American Memorial					P	P	S	P	S		P	P	S
HALE - Haleakala	P		S	S	P	P	S	P	S		P	P	P
HAVO - Hawaii Volcanoes	S	P	S	S	P	P	S	P	S		P	P	S
KAHO - Kaloko-Honokohau	P		S	P	P	P	P	S	P		P	S	S
KALA - Kalaupapa			P	S	P	S	S	S	S		P	P	S
PUHE - Puukohola Heiau			P		P	P	S	P	S		S	S	P
PUHO - Puuhonua o Honaunau	P		P	S	P	P	P	S	P		P	S	S
NPSA - American Samoa	P			P	P	P	S	P	S		P	P	S
USAR - USS Arizona Memorial			P		P							P	P
WAPA - War in the Pacific				S	S	S	S	P	S	S	S	S	S

P = potential; S = self identified

HAWAIIAN ISLANDS

Volcanic Activity

Kilauea, which is currently erupting, and Mauna Loa are two of the most active volcanoes in the world (Parks: HAVO, PUHO, ALKA). In addition, Haleakala (on Maui) and Hualalai (on Hawaii Island) have erupted in the last 400 years (Parks: HALE, KAHO, ALKA). Issues of concern for Hawaii national parks include eruption of lava, pyroclastic materials, corrosive volcanic gases and subsurface thermal heating. Lava flows constitute one of the greatest volcanic hazards (Parks: ALKA, HAVO, PUHO, KAHO, HALE). In Hawaii, lava flows are known to reach lengths of 40 miles (50 km) or more. The flows usually advance slowly enough that people and animals can escape from their paths. Anything overwhelmed by a flow will of course be destroyed. Pyroclastic flows can have the same effect, but the extent of destruction is limited. Pyroclastic flows are emplaced by two methods: cinder and spatter-associated with cone or rampart building at vents, or debris resulting from explosive magma-water (phreatomagmatic) eruptions. Explosive eruptions are not common at Kilauea and Mauna Loa, but they have occurred within historic and prehistoric times. Volcanic emissions can destroy vegetation due to large amounts of emitted CO_2, SO_2 (vog) and HCl (laze) (Parks: HAVO, PUHO, KAHO, PUHE, ALKA, HALE). Acidification of soils, enrichment of heavy metals, killing of vegetation and influence on rainfall are all results of volcanic emissions. Subsurface thermal heating can cause near surface chemical reactions, mineralization and soil transformation which then can influence vegetation type and productivity or potentially kill flora and/or fauna. (Parks: HAVO, ALKA).

Kilauea Volcano, on the island of Hawaii, has been in nearly continuous eruption from the Puu Oo and Kupaianaha vents since 1983 (Parks: HAVO, ALKA). This eruption ranks as the most voluminous outpouring of lava on the volcano's east rift zone in the last two centuries. Since the eruption's onset, lava flows have added 570 acres of new land to the island and paved over 40 square miles (60 km^2) that included rare rainforest, treasured historical sites, and several communities. Kilauea emits roughly 1,500 tons of toxic sulfur dioxide gas (SO_2) each day, making it the largest stationary source of SO_2 in the U.S. "Vog", a locally coined term for volcanic smog, is a visible haze of acid aerosols, unreacted sulfur gases, and fine particulate matter that forms as volcanic and trace species react and become oxidized in the atmosphere. Depending upon wind conditions, vog my be confined to the south and west sides of Hawaii Island, affect the entire island, or even reach the island of Oahu, 217 miles (350 km) to the northwest. In areas distant from Kilauea's gas emission-sources, the vog consists largely of acidic or neutral aerosol (Parks: ALKA, PUHO, KAHO, PUHE, HALE, KALA, USAR), but in areas closer to the source, it contains a potentially more irritating mixture of SO_2 and acid aerosol (Parks: HAVO).

HAVO is situated on lava flows from both Mauna Loa and Kilauea. Those from Kilauea, as described above, as of this writing are currently being emplaced. Mauna Loa last erupted in 1984. PUHO is located on lava flows from Mauna Loa, the youngest of which are 750 years old. KAHO is situated on Hualalai flows that are at least 1,500 years old. The lava flows of PUHE are much older. Within the boundaries of PUHE are flows from Kohala and Mauna Kea that are at least 200,000 years and 120,000 years old, respectively. The ALKA route passes over lavas encompassing the age ranges of all the Hawaii Island parks.

East Maui volcano (Parks: HALE) has witnessed at least ten eruptions in the past 1,000 years, and numerous eruptions have occurred there in the past 10,000 years. Thus, East Maui's long eruptive history and recent activity indicate that the volcano will erupt in the future. The summit area, called Haleakala, has a large depression that looks like a caldera but actually formed by erosion. East Maui is in the post-shield stage. The oldest lava flow exposed on East Maui is about 1.1 million years in age.

Molokai is made up of two volcanoes, Kamakou and Maunaloa, and a small post erosion shield volcano, Puu Uao. KALA is situated on Kamakou and Puu Uao volcanoes, which ceased growing about 1.5 million years ago and 330,000 years ago, respectively. A giant landslide removed much of the northern half of Kamakou forming massive cliffs. After a break of 1 million years, eruptions built a small shield volcano, Puu Uao, against the cliffs forming the present peninsula of Kalaupapa. The Kalaupapa shield is capped by Kauhako Crater which forms a funnel-like pit with a terrace and a lake in the bottom.

Oahu was also formed from two volcanoes, which have now eroded to form the Waianae and Koolau mountain ranges. Both volcanoes are old; the western Waianae volcano ceased growing about 2.5 million years ago, and the eastern Koolau volcano about 2 million years ago, though there has been renewed volcanism ranging from 850,000-32,000 years ago and there is a very slim potential for future eruptions. USAR is located in Pearl Harbor, a series of drowned river valleys formed during successive stages of sea level rise and fall.

Seismicity

Earthquakes in the Hawaiian Islands are closely linked to volcanism and are an important part of the island-building processes that have shaped the Hawaiian Islands. Thousands of earthquakes occur every year beneath the island of Hawaii. Numerous small earthquakes usually accompany eruptions and magma movement within the presently active volcanoes (Kilauea, Mauna Loa, Loihi and Hualalai). They originate in regions of magma storage or along the paths that magma follows as it rises and moves prior to eruption. These are loosely termed volcanic earthquakes (Parks: HAVO, PUHO, KAHO, HALE).

While not as frequent as volcanic earthquakes, earthquakes do occur on the other islands as a result of plate tectonics. These tectonic earthquakes occur in areas of structural weakness or deep within the Earth's crust beneath the islands. In the past 150 years, several strong tectonic earthquakes (magnitude 6 to 8) have caused extensive damage to roads, buildings, and homes, triggered local tsunami, and resulted in loss of life. Additional effects of earthquakes are ground rupture and faulting that leads to ground uplift or subsidence, landslides, rockfalls, mudflows, ground settlement, liquefaction (when sandy or silty ground saturated with water acts like a liquid), and disruption of groundwater flow and surface drainage patterns (Parks: HAVO, PUHO, KAHO, PUHE, HALE, KALA). Figure Five illustrates earthquake hazard zones within the Hawaiian Islands.

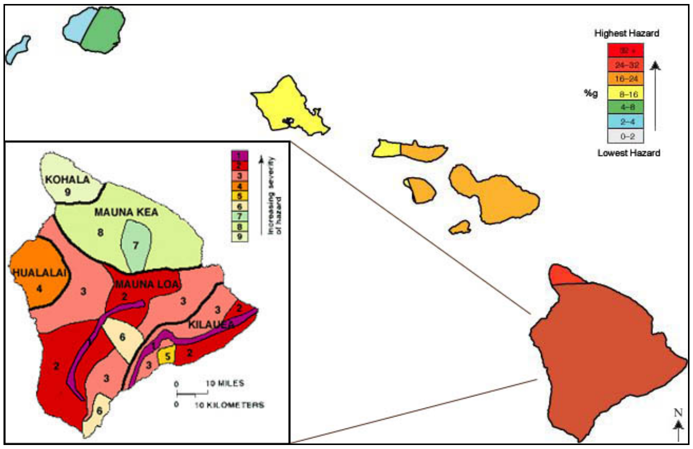


Figure 6. Hawaii Earthquake Hazard Zones (modified from USGS publications).

Tsunami are a significant hazard in the Hawaiian Islands. On average, the Hawaiian Islands experience a tsunami every two years and a damaging tsunami every 5 years (Dudley and Lee 1998). Since 1837, 33 tsunami, at least four of which were locally generated, have struck Hawaii with varying severity. On April 1, 1946, a tsunami generated by a magnitude-7.8 earthquake in the Aleutian trench struck the Hawaiian Islands and caused 159 fatalities. On April 2, 1868, an estimated magnitude-7.9 earthquake generated beneath the southeast flank of Mauna Loa produced waves that swept coastal villages from Ka Lae to Kumukahi, killing 75 residents. These two events represent the end members of tsunami that can affect Hawaii – those that are generated by large earthquakes in subduction zones around the Pacific Rim and those that are generated by large local earthquakes. Tsunami can cause erosion along the coastline, damage to reefs, and saltwater inundation to nearshore habitats (Parks: HAVO, PUHO, KAHO, PUHE, ALKA, HALE, KALA).

Erosion/Mass Wasting

Erosion is the process of rock disintegration by either chemical or mechanical means or the wearing away, or removal by wind, water or man. On the windward side of the islands, water is the main force driving erosion. Anthropogenic changes to the landscape, including introduction of feral ungulates and invasive alien plants, can increase erosion due to disturbance of the groundcover. On the leeward side of the islands, wind erosion can be a major problem when combined with destructive land-use practices. Erosion can scour stream beds and banks and transport sediment to the marine environment, resulting in changes to turbidity, deposition cycles, reduced productivity or health of soil, plants and aquatic animals (Parks: HAVO, PUHO, KAHO, PUHE, HALE, KALA).

Mass wasting is another hazard in Hawaii. The presence of many steep pali (cliffs, themselves formed by landslides, erosion and ground movement) combined with subsurface water, excessive precipitation and earthquakes can lead to additional landslides, mud flows or soil creep. This instability results in burial of habitat, increased erosion rates and disruption of hydrology (Parks: HAVO, PUHO, KAHO, PUHE, HALE, KALA).

In Hawaii, two general types of slope failures have been identified: slumps and debris avalanches. Slumps are slow moving, up to 25 miles wide and over six miles high or deep, with transverse ridges and steep toes. Hilina Pali in HAVO is an example of a slump in progress. .Debris avalanches are fast moving, long (more than 140 miles) rather than wide and much thinner (0.3 mile to 1.25 miles). They commonly have well-defined amphitheaters at their head and hummocky terrain in their lower part. Each debris avalanche is thought to represent a single episode of catastrophic slope failure. The great sea cliffs of the north shore of Molokai are the remnants of a colossal debris avalanche called the Wailau slide (Parks: KALA).

Debris flows, earth slides, and rock fall are quite common on Oahu and probably the other islands; although they are much smaller than the debris avalanches, they are still quite destructive. The New Year's Eve storm of December 1997 and January 1998 on Oahu caused more than 400 landslides and most of these mobilized into debris flows. The remainder were slow-moving earth slides, which caused millions of dollars in property damage. Rock fall in May 1999 at Sacred Falls State Park on Oahu killed eight and injured many other park visitors. These forms of mass wasting also have potential to cause environmental damage or change in Hawaii's National Parks and to endanger visitors. In May of 1999, a major landslide occurred just east of the Pelekunu Valley on Molokai. Originating near the top of 2,500-foot high cliffs, the avalanche carried enough rock and soil debris to spill out into the ocean and create about six acres of new land.

Littoral/Marine

Beach loss and coastal erosion.

Coastal erosion, the landward displacement of the shoreline, and beach loss, the removal of sediment from the subaerial (submerged) and intertidal beach, are widespread and locally severe problems in Hawaii and other Pacific Islands. The causative factors are poorly understood and probably include complex interactions between a number of variables such as: catastrophic storms, accelerated sea-level rise, adverse effects of coastal engineering structures, and interruption of sediment supply. Other results of coastal erosion include instability of seacliffs, damage to shallow reefs, and inundation of low-lying areas. Low-latitude coastal environments are unique because they rely upon carbonate production from living organisms of shallow reefs in addition to land-based erosional debris. Reef viability, and hence water quality, is therefore critical to the natural maintenance and balance of the coast and its beaches. Beaches are important to Pacific islands for several reasons: a) Beaches provide a natural buffer that help protect coastal lands during storms. b) Beaches are an economic and recreational resource and are a valuable attraction to visitors and locals alike. Even though many of the island national parks have a cultural or “other” theme, if they contain beach resources within their boundaries they are often heavily utilized. c) Beaches are a valuable cultural resource to Pacific island people. d) Beaches are an important habitat for a variety of creatures including shorebirds and sea turtles.

Future coastal evolution and vulnerability to change is difficult to predict because many factors are involved. For coastal regions, vulnerability to sea-level rise is based on the relative contributions and interactions of six variables: Tidal range, which contributes to inundation hazards; Wave height, which is linked to inundation hazards (in Hawaii, waves are influenced by several sources – trade winds, north pacific swell, Kona storm swell, southern swell); Coastal slope (steepness or flatness of the coastal region), which is linked to the susceptibility of a coast to inundation by flooding and to the rapidity of shoreline retreat or advance; Historic shoreline change rates, which indicate how fast a section of shoreline has been eroding or accreting; Geomorphology, which indicates the relative erodability of a section of shoreline; Historical rates of relative sea level (RSL) change, which correspond to how the global (eustatic) sea-level rise and local vertical land motion, such as tectonic uplift or subsidence, have affected a section of shoreline. In Hawaii, RSL is most affected by lithosphere subsidence due to volcanic loading (Parks: HAVO, PUHO, KAHO, PUHE, HALE, KALA). Many of these variables have not been monitored in these parks, so predictions of future change will be restricted by minimal data for these factors.

Over a longer time scale, there is a growing consensus that human activity is greatly accelerating the rate of climate change. Although predictions are variable, many forecasts indicate that carbon dioxide in the atmosphere will double by 2050. The predicted consequences are a sea-level rise of about 1 foot, a 30 percent decrease in coral reef growth, and most important, increased climatic variability. This will cause both the frequency and intensity of extreme climactic events to increase. For coastal areas and small islands, saltwater encroachment and inundation will increase because of rising sea levels and increased storm activity

Primary coastal features of Hawaii include beaches, low-lying rocky shorelines, stream mouths, steep rocky headlands, and heavily developed shorelines. Shorelines are further modified by the presence of reefs, embayments, wetlands, streams and minor development. Typical reef growth within the Hawaiian coastal zone consists of a thin veneer (1-2 m) of coral-algal growth on either a volcanic rock platform or antecedant Pleistocene limestone foundation. Most beach sand in Hawaii is composed of bioclastic carbonate grains derived from the skeletons of corals, mollusks, algae and other reef-dwelling, carbonate-producing organisms. (Olivine & black sand beaches have volcanic sources). Sand supplies are limited in comparison to mainland beaches, which derive their sand from terrestrial sources. Reduced sediment supply, large storms, RSLR, and construction of shoreline hardening structures (Parks: PUHE, KAHO) contribute to coastal erosion

Coastal Hazards (Tsunami, Extreme Storms, Coastal Stream Flooding).

The Pacific Island parks have the potential to be severely impacted by marine inundation from tsunami and extreme storms, and freshwater inundation by coastal stream flooding during high rainfall events. Tsunami pose a significant hazard in the Pacific Islands coastal zone. For example, during the tsunami of 1946, generated by an earthquake in the Aleutian Islands, 159 people in the State of Hawaii lost their lives including fifteen children and five teachers at Laupahoehoe Peninsula where a 9 m (30 ft) wave washed over the low-lying headland along the east coast of the island of Hawaii. According to Dudley and Lee (1998), Hawaii has experienced a total of 95 tsunami in 185 years (1813-1998), or on average one every two years with a damaging tsunami every five years.

Tsunami are caused by the sudden movement of the seafloor in response to faulting, landsliding, or submarine volcanic eruptions or collapse of volcanic edifices. The seafloor movement generates a number of long-wavelength waves that travel across the ocean unimpeded until they reach the coast. Tsunami can either be locally generated or originate far afield throughout the Pacific Ocean basin. Locally generated events are especially hazardous because of the limited warning time. It is thought that catastrophic tsunami were locally generated during the early geologic history of the Hawaiian Islands when massive portions of the young islands slid into the sea (Moore et al., 1989). More recently, tsunami that have impacted the Hawaiian Islands have been generated far afield and have taken several hours, or longer, to reach Hawaiian shores. The geography of the shoreline plays an important role in the form of the tsunami. Tsunami manifest predominantly as a rapidly rising sea level, and less commonly as large breaking waves (bores). Tsunami may be very large in embayments, typically experiencing amplification in long funnel-shaped bays. Fringing and barrier reefs appear to have a mitigating influence on tsunami by dissipating wave energy. The high degree of volcanism and seismic instability in and around the Pacific basin has led to a long history of tsunami occurrences.

Coastal stream flooding is common in watersheds in the Pacific Islands. Streams are typically small and are characterized by steep slopes with little channel storage. Consequently, intense rainfall events often result in a rapid rise of water level and flash flooding. Coastal flooding of low-lying areas and rapid discharge of sediment into littoral environments are common effects of intense rains. Floods caused by heavy rainfall and strong winds typically occur during the rainy season, although heavy rainfall can also be associated with the tropical storm and hurricane seasons. Regions of high precipitation are typically characterized by deep valleys that channelize floodwaters thereby reducing flooding. Elsewhere, the high porosity of the volcanic and limestone rocks lead to high infiltration rates and are a deterrent to frequent flooding.

High seasonal wave energy and overwash associated with the passage of extreme storms are the main causes of marine inundation in Pacific Islands. Sudden high waves, and the strong currents they generate in the nearshore region, are one of the more consistent and predictable coastal hazards. The Oahu Civil Defense Agency classifies high surf as a condition of very dangerous and damaging waves ranging in height from 3-6 m (10 ft to 20 ft) or more. These waves result from open-ocean swell generated by storms passing across the Pacific. High surf conditions on the northern shores of all islands are most common during the northern hemisphere winter while high surf on the southern shores occurs most commonly in the summer months when storms to the south, including southern hemisphere tropical cyclones, generate wave heights in the range of 1.2-4.5 m (4 to 15 ft). Tradewind generated waves, usually less than 2 m in height, occur throughout the year along all windward (east) coasts. The leeward (western) shores can receive wave energy from the north or south depending upon local orientation and exposure. Damage to coastal resources associated with tropical storms is the result of high wind, extreme waves and marine overwash, and locally heavy precipitation.

The knowledge of tropical cyclone behavior in the central Pacific has been greatly improved by satellite technology that allows us to track storms across the vast oceans. More commonly, “near-misses” that generate large swell and moderately high winds causing varying degrees of damage are the hallmark of hurricanes passing close to the islands. Impacts from these “near-misses” can be severe and lead to beach erosion, large waves, high winds, and marine overwash, despite the fact that the hurricane did not make landfall. For example, communities on the Waianae (leeward) coast of Oahu suffered severe damage from hurricanes Iwa and Iniki, yet the eye of neither storm actually made landfall on Oahu. Storms directed on one side of an island may have significant impact on the other side. Studies in the aftermath of Hurricane Iniki and Typhoon Russ on Guam, showed the greatest threat related to hurricane overwash in the Pacific Islands with narrow insular shelves is due to water-level rise from wave forces rather than wind forces (Jaffe and Richmond, 1992; Fletcher et al., 1995). This differs from areas with wide shallow shelves, such as the east and gulf coasts of the U.S., where wind set-up or storm surge is the primary type of elevated water levels. During Iniki, the strongest component of the overwash was the result of large waves causing extreme wave run-up and set-up. Other factors influencing coastal overwash are low atmospheric pressure (relatively minor factor), tidal stage, coastal topography, and location relative to the eye of the hurricane

Soil

Soils differ from place to place for a variety of reasons that include: variations in the parent material; local climate; slope and drainage conditions; nature of organic debris added to developing soil; biota; and length of time soil is exposed to weathering processes. While similar soil formation processes operate worldwide, consistently warm temperatures accelerate weathering in Hawaii. Soils are generally thin or absent on the rift zones and slopes of Kilauea and Mauna Loa (Parks: HAVO). Immature soil horizons have developed on Mauna Kea, and mature soil horizons have developed throughout the rest of the Hawaiian Island chain (Parks: KALA, HALE, ALKA, PUHE, PUHO, KAHO). Generally, dry climate soils tend to be poor in organics and chemically weathered products (lee sides of the islands). Wet climate soils are rich in organics and chemically weathered products (windward sides of the islands). Chemical weathering processes predominate where precipitation is high, and physical weathering processes predominate where precipitation is low.

Generally, lava flows less than 10,000 years old are only slightly weathered, little or no soil has formed on them, and their surfaces have not been modified by erosion. Ground cracks and groundwater break up flows so that plant roots can take hold. Cyanobacteria are the first organisms to live on a new lava flow and lichens come next. Later, grass, ferns, and moss work to turn the lava into soil. These soil-making forces work faster on the wet, windward sides of the islands than on the dry, leeward sides. Chemical reactions between water and the silicate minerals in the basalt produce clay of various types. Weathering of the parent rock is the major source of most plant nutrients in young sites, but the more readily weathered minerals are depleted by 20,000 yr, and soil fertility declines in the oldest sites. The supply of available nitrogen limits plant production early in the sequence, while phosphorus supply limits production in older sites.

Hydrology

To understand the hydrology of an area, one must first understand the area's climatology and geomorphology. Hawaii has a wide range of climatological zones that depend on elevation and geographic position for each individual island. The windward or northeast facing sections of the islands generally have a consistent year-round supply of trade winds that bring brief showers (Parks: HAVO, HALE, KALA). The wetter period of the year in windward areas depends on the individual island and the elevation, but generally occurs in the spring months. The highest peaks, such as Mauna Loa on the big island of Hawaii, receive several inches of snowfall, and the landscape can appear more alpine than tropical (HAVO). The leeward (west) sides of the island are more arid (Parks: ALKA, HAVO, HALE, KAHO, PUHO, PUHE). Generally, rainfall at various locations in the state ranges from less than 10 inches to more than 400 inches (25-1015 cm) annually. Severe droughts are associated with El Nino cycles, but may persist for years beyond El Nino events.

Watersheds in Hawaii are typically small, and are characterized by steep slopes with little channel storage. Streamflow rises quickly during storms. Watersheds on the windward sides of islands tend to have perennial streams sustained by groundwater discharge, whereas leeward watersheds typically have ephemeral streams. In some areas, such as portions of Kauai and the Big Island of Hawaii that are basically uninhabited, soil type and vegetation are extremely variable and will dictate the amount of surface water runoff that is expected. In particular, the presence of an ash layer will serve to increase runoff. All drainage basins in Hawaii, given the right meteorological conditions, can produce dangerous flash floods. Coastal flooding of low-lying areas and rapid discharge of sediment into littoral environments are common effects of intense rains.

Each of the Hawaiian Islands has groundwater available in some locations depending on the age and the geologic structure of the island. Most aquifers are unconfined. Variability in geologic settings, rock permeability, and recharge results in groundwater occurrence ranging from thin lenses of brackish water underlain by saltwater to vertically extensive freshwater bodies. The permeability of volcanic rocks is variable and depends on the mode of emplacement, amount of weathering, and thickness of the rocks. In Hawaii, the major fresh groundwater systems are either freshwater-lens or dike-impounded systems. Minor perched systems can exist above the lowest water table. In younger areas, groundwater is contained in thin-bedded aquifers that are highly susceptible to contamination. In several parks, increasing development adjacent to or upslope from park boundaries has led to concerns of groundwater contamination (particularly KAHO).

The main factors limiting groundwater availability are saltwater intrusion, the reduction of discharge to streams and the ocean, and lowering of water levels. Groundwater withdrawal ultimately reduces the amount of discharge to springs, stream, or the ocean by the amount that is withdrawn. Reduced discharge leads to loss of habitat for native aquatic species, disrupts aquaculture practices in coastal fishponds and encourages saltwater intrusion into the freshwater system. Groundwater is ecologically and culturally important in all Pacific Island National Parks. Groundwater sustains coastal springs and wetlands, supplies a component of freshwater to native Hawaiian fishponds, and in some areas of the state contributes to perennial streamflow. Streams and wetlands are habitat for endangered and native species. Hydrologic processes are highly variable over short intervals of space and time, and multiple demands for limited resources have reinforced the need for scientifically sounds approaches to water management. For example, USGS has used numerical models to estimate the reduction in discharge to wetlands in the KAHO that may be caused by possible groundwater withdrawal (for more information on West Hawaii parks water issues, see http://www.nature.nps.gov/im/units/pacn/monitoring/plan/waterq/wq-mtg_20030812.pdf). Increasing development adjacent to and upslope from the park is a concern for increased erosion and sedimentation, coastal pollution and contaminated groundwater.

The Waikolu Valley of KALA contains the park’s sole perennial stream. Portions of the Waikolu Stream flow have been diverted to drier areas of the island. It is estimated that up to 20 percent of the annual water yield from the Waikolu watershed is diverted. These diversions have caused adverse effects on riparian and biotic resources (Brasher 1997).

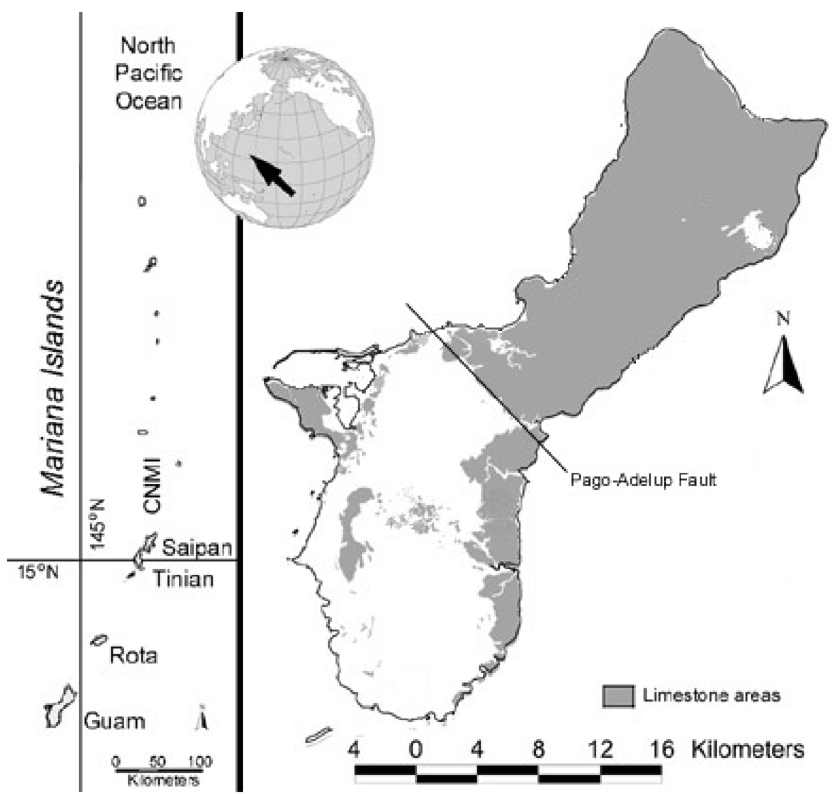
MARIANA ISLANDS

Geology/Volcanic History

Two volcanoes formed Guam, although much of the island is characterized by Karst topography. Guam is divided into two major physiographic provinces (Figure 7): southern Guam, a rugged volcanic highland with some limestone outliers, and northern Guam, an undulating limestone plateau with two volcanic inliers. Limestone is exposed on the islands due to uplift associated with the subduction of the Pacific plate.

In the southern half of Guam, weathered volcanic rocks dominate the land surface. The volcanic rocks in Guam are older and of a different composition than those found in the Hawaiian Islands. Late Middle Eocene (36-58 m.y.) pillow lavas, breccias and dikes record early stage island-arc volcanism. Subsequent volcanism in the late Eocene to Middle Oligocene (22.5-36 m.y.) produced an overlying unit of breccias, tuffaceous sandstones, flows and sills. These two units are unconformably overlain by a Late Miocene (6-22.5 m.y.) volcaniclastic unit containing occasional limestone fragments indicating that a shallow carbonate depositional environment existed nearby. Carbonate remnants and outliers of shallow-water carbonate deposits top the high points of the underlying volcanic units.

Figure 7. Guam carbonate areas (modified from D. Taborosi and J.W. Jenson, 2002)



In the northern half of Guam, limestone overlays volcanic rocks to depths of several hundred feet and extends below sea level. The limestone is heavily weathered, highly permeable, and exhibits many karst-like features.

Saipan is similar to Guam in that it is mainly composed of limestone resting on a volcanic core. It is a composite island with a central highland of Eocene and Oligocene volcanic and volcanic-derived sedimentary rocks interfingering with, and mantled by, limestone of Late Eocene to Pleistocene age. AMME is built on deposits of recent age composed of marine limestone, beach and marshland.

There is no evidence of recent volcanic activity in Guam or Saipan. However, several active submarine volcanoes are located near Saipan. The Ruby Seamount is located 25 miles (40 km) northwest of Saipan. The last eruption was in 1995. Ruby Seamount is located 200 feet (60m) below sea level. The larger Esmeralda Bank, 24 miles (28 km) west of Tinian rises to within 100 feet (30m) of sea level. Six possible eruptions have been reported at Esmeralda Bank since 1944. In the early part of the 20th century the banks were reported to be above sea level but subsided as a result of an earthquake.

Other volcanic hazards for Guam and Saipan come from the presence of active volcanoes to the north. Anatahan is the closest active volcano above sea level, 80 miles (129 km) from Saipan. The last eruption at Anatahan started on May 11, 2003. There is a low risk of ash fall and tsunami generation from eruptions in the northern islands.

Seismicity

Guam and Saipan have evolved in a tectonically active area with many episodes of uplift and subsidence. These episodes, with associated normal faulting, have been ongoing prior to, during, and subsequent to carbonate deposition. Seismicity in the region results from the convergence of the Pacific plate and the Philippine Sea plate. The Pacific plate is subducting beneath the Philippine Sea plate at a rate of about 5 cm per year producing several significant tectonic features including, the Mariana Trench and the Mariana Ridge. The Mariana trench marks the surface contact of the Pacific plate and Philippine Sea plate.

Earthquakes are common and include large magnitude events, for instance a magnitude 8.0 in August 1993 and a magnitude 7.2 in April 2002. Earthquakes in the magnitude range 5-6 occur at a rate of 5 to 8 per year along the Mariana trench, while earthquakes in the magnitude range of 6-7 occur only on average once in ten years. The August 1993 earthquake caused several small landslides at WAPA and also caused some minor cracks to appear in the visitor center's concrete walls. Several major hotels outside the park were destroyed.

Guam has had only three tsunami causing damage at more than one location in the past 200 years. Locally caused tsunami occurred in 1849, 1892, 1990 and 1993 while tsunami in 1952 and 1960 were from Kamchatkan and Chilean earthquakes respectively. The high angle of the subducting Pacific plate ensures that most of the locally generated earthquakes are deep and therefore less likely to generate tsunami. The only area likely to cause tsunamigenic earthquakes is east of the Marianas in a shallow dipping region of the subduction zone. Locally generated tsunami pose a slight risk to Saipan and Guam due to active volcanoes to the North and West of the islands. For instance, tsunami warnings were issued for Saipan during the eruption of Anatahan in 2003 and Ruby Seamount in 1995, although no tsunami occurred.

Erosion/Mass Wasting

Erosion occurs when rain or flowing water dislodges and transports soil particles, organic matter, and plant nutrients. Erosion is a particular problem for WAPA, especially sedimentation on the reef flats and coral reefs. In recent years, Guam's rate of soil erosion has increased dramatically due to new road construction and 'badlands' created by grazing and range fires. Most erosion problems come from a small area during infrequent short-term events, such as a typhoon. There is an extensive erosion problem on the volcanic soils of southern Guam but it is not a serious problem on the limestones of northern Guam. In southern Guam, repeated fires have led to the soil being eroded to saprolite where only bare land remains or only grass can grow. Bare areas, concentrated on ridges and slopes, can get super-saturated and experience slumps and creep.

Erosion carries away soil resources, reduces soil fertility, and produces thousands of tons of sediment that degrade water quality. Soil and sediment may convey pesticides, harmful bacteria, toxins, and nutrients into surface waters and groundwater. Additional problems associated with erosion include reduced water storage capacity in streams and lakes, loss of wildlife habitat and sedimentation on reefs. The greatest resource at risk is the lagoon ecology, especially for WAPA and AMME.

Most of Saipan is limestone with high permeability, which limits erosion. Erosion problems occur during infrequent short-term events, such as typhoons. Mid island areas with volcanic soil are starting to look similar to Guam with bare areas and slump/creep problems.

At WAPA, several small landslides occurred within the park during the magnitude 8.0 earthquake in 1993 due to ground shaking and heavy rains associated with the coincident tropical storm. Many of the earthquakes in Guam have occurred at the same time as passing tropical storms or typhoons, leading to increased erosion, landslides and slumping.

Littoral/Marine

Guam and Saipan are located in a very active area for typhoon occurrence with over 19 major storms passing over Guam in the last 60 years. The most recent major storm to strike Guam, Super Typhoon Pongsona, caused extensive damage to WAPA. Dozens of storm surges related to typhoons have caused hundreds of millions of dollars of damage on Guam and Saipan. The beach at AMME is usually washed over during typhoons and tropical storms, such as in typhoons Ryan-1992, Gay-1992, Wilda-1994, Keith-1997, Winnie-1997, and Paka-1997. A result of storm surge and overwash is erosion of beaches and reefs, deposition of debris and rocks, and destruction of built structures. Storm surge associated with Typhoon Ryan removed at least 15 feet of sand from Micro Beach at AMME in 1992. Storm surge at WAPA during super-typhoon Paka in 1997 resulted in the visitor center basement being flooded, chain link gates being swept away and rocks and debris being deposited on the beach during super-typhoon Pongosa in December 2002. On Guam, the bordering fringing reefs in the south are broader than in the north. Two large barrier reef systems occur at Cocos Lagoon and at Apra Harbor. These reefs are extremely valuable in terms of marine life, aesthetics, food supply, recreation and protection of Guam's highly erodable shorelines from storm waves, currents and tsunami. The physical structure of the coral reef provides a natural breakwater, which retards shoreline erosion and provides for the replenishment of beach sand. On Guam, soil erosion and sedimentation from military, resort, and residential development stress corals. Near urban centers and Apra Harbor, coral reef ecosystems are degraded by sewage, thermal discharges, and port construction. In some areas tourist impacts are evident. Natural disasters such as heavy wave action, cyclones and earthquakes disturb coral reef growth. Although there have been no recent destructive tsunami in Guam, there is evidence for historical tsunami impacting the island. In WAPA, there are several kinds of shoreline: sandy beach, cliffed, dredged, and armored.

At AMME, beach erosion and coastal wetland preservation are high priority issues. The wetland at AMME is important for several reasons. Wetland environments provide critical habitat for many wildlife species and are important in curbing erosion and contributions to flood control. Through mitigation of erosion and flooding they provide for the protection of nearshore areas from pollution and sedimentation. The AMME wetland is the only remaining wetland of its type on Saipan. Micro Beach at AMME is a highly utilized beach park.

Soil

Nineteen different soil series have been mapped on Guam and are described in the Natural Resources Conservation Service (NRCS) 1988 publication "Soil Survey of the Territory of Guam". NRCS also has a soil map of Saipan, published in 1989. The soils of Guam and Saipan can be grouped into three primary categories: soils over limestone (pure or clay rich), soils on volcanic uplands, and soils on bottomlands and coastal margins. The predominant location of limestone-derived soils is in northern Guam and the predominant location of volcanic soils is in southern Guam. In Saipan, profile development is generally incomplete, except in certain red clay soils of the uplands, reflecting rapid erosion under warm moist climatic conditions.

Soils formed from the weathering of limestone are comprised of the residual insoluble minerals that have accumulated as the limestone dissolves. In this solution process the resulting soils are highly leached and, therefore have fertility problems. Volcanic soils average 8-16 inches (20 to 40 cm) deep with thicker accumulation on valley floors and narrow coastal plains. The general process of soil formation is the transformation of volcanic material to clays. Yearlong high temperatures and high rainfall combine to accelerate clay formation and the removal of nutrients.

Geological studies in Saipan include Cloud et al. (1958 and 1959). Cloud (1955) conducted beach and terrain analysis, and Eldredge and Randall (1980) studied Saipan’s reefs and beaches. Cloud (1959) analyzed submarine topography and shoal water ecology. Other studies include a subsurface soil investigation of Smiling Cove Marina (Geotesting 1987), topography, geology, and related water resources (Cole and Bridge 1953), general geological surveys (McCracken 1953 and Young 1989), limestones (Johnson 1957), and volcanic rocks (Schmidt 1954 and 1957). Siegrist (1989) evaluated a potential source of fine-aggregate in limestone bedrock deposits located in northeastern Saipan, following an earlier extensive geologic reconnaissance and sampling-testing program carried out in 1988. Soils were studied by McCracken (1957), and McCracken and Zarza (1958); the Natural Resources Conservation Service (1989) has published soil maps for Saipan. Hydrological studies include Davis (1958), Tenorio Engineers (1973), and van der Brug (1985). Paleontology studies include calcareous algae (Johnson 1957), discoaster (Bramlette 1957), radiolarian (Reidel 1957), foraminifera (Todd 1957 and Cole 1957), and echinoids (Cooke 1957).

Hydrology

Annual precipitation of the Mariana Islands, which averages between 80 to 100 inches (200 and 250 cm), is strongly seasonal with heavy rains from July through October. Trade winds are fairly constant, but there is often a weak westerly monsoon influence in summer. The Marianas are also subject to frequent severe storms and typhoons, averaging about one typhoon per year. During ENSO (El Nino/Southern Oscillation) years, drought can be severe.

On the northern half of Guam, the limestone is heavily weathered, highly permeable, and exhibits many karst-like features. A limestone aquifer, the Northern Guam Lens, is the main source of fresh water because there is very little direct surface water runoff and no perennial streams. The water table rises from sea level at the coast to tens of feet in the interior. Fresh water discharges at coastal springs and seeps, except at the southern end near the Pago-Adelup fault. Here, the Fonte and Pago Rivers follow the volcanic terrain opposite the fault and then turn to run parallel to it. In the southern half of Guam, the volcanic rocks are characterized by low permeability and the water table can rise to hundreds of feet above sea level. In the southern limestone remnants, water discharge from springs into streams determines the local base flow. In some cases, a stream may alternately gain and lose base flow as it passes from volcanic to limestone terrain.

Saipan has a volcanic core that is mostly below sea level and overlain by limestone. The limestone is of late Tertiary and Pleistocene (110 ka-65 m.y.) age and is the principal source of groundwater. It surrounds and overlies the relatively impermeable Eocene volcanic rocks, which form the core of Saipan. As a result, both high-level and basal unconfined aquifers are present. Tectonic deformation, primarily as high-angle normal faults, has created separate carbonate aquifer compartments on the island. The perimeter of the island, and inland scarps, contain abundant caves at similar elevations that mark a past sea level. The relative sea level has dropped to its current level as a result the interaction of local tectonic uplift and global ice ages. Several springs and resurgent streams are present, however, the typical discharge from aquifers is either below current sea level, or is distributed along the coast as diffuse flow. There is very little direct runoff except during large storms.

Due to the high permeability of carbonate systems on Guam and Saipan, there is high infiltration. Land use can lead to contamination of groundwater supplies. Storm events flushing through the system cause contamination. Precipitation on raised limestone islands quickly moves downward through the porous rocks and along openings formed by dissolution along joints and bedding planes.

AMERICAN SAMOA

Volcanic activity

The Samoan shield volcanoes are younger toward the eastern end of the island chain. Tutuila formed from four dome-shaped volcanoes erupted between 1.0 and 2.6 million years ago. Current hot spot volcanism is centered over Vailuluu Seamount, located 28 miles (45 km) east of Tau island, the easternmost island of the Samoan chain (Figure 4). Vailuluu rises to a height of within 1,936 (590 m) of the sea surface. The last known eruption occured July 10, 1973 and possibly 1995, when an earthquake swarm occured. The most recent eruption on the main islands occurred along the ridge connecting Olosega with Tau Island. This submarine eruption took place in 1866; 2 miles (3 km) SE of Olosega.

The islands of Samoa are just northeast of the Tongan trench, a place is where the Pacific plate is subducting under a bend in the Australian plate. The presence of the subduction zone plausibly explains the unusual rift zone that occurs along the whole of the Samoan chain. The Western Samoan islands have had historical eruptions along the rift zone.

Seismicity

Compared to most areas in the Pacific along the Ring of Fire, American Samoa is seismically quiet. The entire Samoan archipelago lies 60 miles (100 km) northeast of the Tonga Trench, where the Pacific Plate subducts under the northeastern corner of the Australian Plate. Most earthquakes occur along this plate margin, near Tonga.

Large tsunami events are rather rare, as the Mariana plate plunges to great depths quickly, diminishing the risk for a large earthquake as a result of the small seismogenically coupled portion of the plate interface. In 1995, an 8.0 magnitude earthquake in the Tonga Islands caused a 30 cm tsunami at Pago Pago. In 1999, a 7.3 magnitude earthquake in Vanuatu caused a 20 cm tsunami at Pago Pago.

Erosion/Mass Wasting

The islands of American Samoa are severely eroded with steep cliffs and deep valleys. Much of the water from rainfall runs off in streams rather than percolating into the ground due to the steep slopes. Soil being eroded off the islands and deposited in nearshore waters is a common problem on the south side of Tutuila Island due to anthropogenic impacts, but can also occur in localized area near villages adjacent to the park. In addition, heavy rains from tropical storms or typhoons can cause flooding, mudslides and landslides. Rainfall amounts are ~100-120 inches per year at the coast, and ~200 inches per year in the interior mountainous areas. Landslides occur in such areas where slopes are steep and heavy rains can saturate the weathered zones.

Due to the traditional communal land tenure in American Samoa, the park area is leased from surrounding villages. Although most park areas are forested, subsistence use of the land and water resources is allowed. Because of this, small-scale farms along streams may add to sediment loads. Feral pigs and roads may also add to the erosion problem. Erosion carries away soil resources, reduces soil fertility, and produces thousands of tons of sediment that degrade water quality. Soil and sediment may convey pesticides, harmful bacteria, toxins, and nutrients into surface waters and possibly release them into groundwater. Additional problems associated with erosion include reduced water storage capacity in streams and loss of wildlife habitat. In NPSA, one important resource at risk to erosion is the lagoon in the park unit in Ofu.

Littoral/Marine

Marine ecosystems are an important part of NPSA. Coral reef ecosystems are productive biologically and geologically. An active reef can build islands such as atolls, and erosion and deposition by waves and biologic action can create sand deposits and beaches. If the reef-building processes are disturbed, however, erosion will dominate and the reef will deteriorate. Natural disasters such as storm waves, cyclones, and earthquakes may disturb coral reef growth. Land clearing, agricultural development, dredging, overfishing, and tourism are some of the human factors that affect reefs. Perhaps the major threat to reef-building processes is the increase of dissolved carbon dioxide in coastal waters due to global warming. This increase may slow coral growth and erode the coral matrix. Samoans traditionally do small-scale sand mining of beach deposits for use around their homes and sand mining, especially in the Ofu park unit, is a continuing problem for the park. The Samoan islands are infrequently affected by tropical cyclones and tsunami. The most recent cyclone to pass Tutuila was Heta (January 2004) which caused some disturbance to the island shorelines and reefs and prompted the island to be declared a Federal Disaster area. The 1960 Chilean Earthquake caused a 2.5m tsunami at Pago Pago which caused some local damage.

Soil

Soils formed in hot, wet tropical areas have significant fertility problems. Chemical weathering of parent rock materials is the predominant soil forming mechanism. High temperatures, high precipitation levels and the action of plant roots combine to accelerate leaching of nutrients from rock and soil mineral particles. Soils on steep slopes, such as in American Samoa, are likely to be rocky and thin.

Hydrology

The climate of Samoa is tropical, moderated by strong S.E. trade winds from May to November. During the balance of the year (Samoan summer and fall) the winds are variable, with severe storms and occasional hurricanes. This is called the wet season, although in places, like Pago Pago, where mountains intercept the trade winds, it may rain throughout the year. Yearly rainfall: Apia 108 inches (274 cm); Pago Pago, 197 inches (500 cm). During ENSO years, drought conditions are usual.

In American Samoa, Tutuila island is mostly comprised of low-permeability rock. Ofu and Olosega may be similar to Tutuila, but not enough is known about the hydrogeology of these islands to make a definitive statement (Izuka, USGS-WRD, pers. commun, 2004). Evidence suggesting the existence of very-high permeability rocks exists on Tau, but some wells on that island have penetrated low-permeability rock as well. Enough data exists about the hydrogeology of Tutuila to generally state that most of the island is comprised of low-permeability rocks, save for the Tafuna-Leone plain which has a relatively high permeabililty (Izuka, USGS-WRD, pers. comm., 2004). Where rocks have low permeability, it is possibly due to the older basalts weathering to clay-type minerals which would decrease the permeability. In general, the alkalic nature of the lava flows that comprise the islands of Samoa differ from those of Hawaii in being thicker, and therefore having a lower permeability. Along with numerous large intrusive bodies found in Samoa, these alkalic lavas lend a lower permeability to the islands of Samoa than the Hawaiian Islands. Aquifers are located in thin-bedded basalt flows, tuff, and cinder, as well as in underlying beach and lagoonal sedimentary deposits. Aquifers are basal-type with freshwater lens floating on salt water. Groundwater on Aunuu, Tau, Ofu, and Olosega occurs as basal groundwater and as perched water. On Tutuila, there are two main geo-hydrologic units. The larger one comprises 75% of the island and has low to moderate permeability. The other unit is found in the Tafuna-Leone plain and is the main source of drinking water for the island. Saltwater intrusion is a significant threat to the basal groundwater, especially during ENSO years.

Streams are relatively abundant on Tutuila but tend to be small and compact (generally less than two miles). During heavy rainstorms, large amounts of water will run off because of low permeability, steep slopes, small watershed size, and sometimes because of the small total amount of water holding capacity of aquifer rocks. Flash flooding in narrow stream valleys results from short duration, high volume rainfall events.

MONITORING

VOLCANIC ACTIVITY

Hawaii

Eruptions are almost always preceded and accompanied by volcanic unrest, indicated by variations in the geophysical and gas geochemical state of the volcanic system. The U.S. Geological Survey's Hawaiian Volcano Observatory (HVO) has an extensive monitoring program covering lava flows, deformation, seismicity and volcanic emissions on the islands of Hawaii and Maui. Monitoring partnerships with the Center for the Study of Active Volcanoes (CSAV) and other academic institutions (such as University of Hawaii and Stanford University) help HVO fulfill its mission to use scientific methodology to understand the nature of volcanic processes and to reduce their risks to society.

Geologists at HVO track the advance of active lava flows using GPS mapping aids and aerial photographs. Observatory scientists keep detailed descriptions and photo archives, including still and video images, to better understand and forecast future eruptions (Parks: HAVO). Lava, spatter, and other erupted material are sampled for geochemical and mineralogical study (Parks: HAVO, HALE). Geodetic surveys are taken to precisely depict the growth of flow fields, vents and changes in ground deformation associated with volcanic activity (Parks: HAVO, HALE, PUHO, PUHE, KAHO). In addition, they monitor the volcanoes through direct visual observations of eruptive activity, changes in electrical and magnetic properties, and changes in gravitational attraction (Parks: HAVO).

At Kilauea (HAVO), sulfur dioxide (SO_2) emission-rate measurements have been collected nearly weekly since 1979 using a correlation spectrometer (COSPEC). These measurements constitute an unusually complete data set. Chemical analysis of gas samples taken from volcanic vents at the summit and rift zones of Kilauea and Mauna Loa has helped to improve models of how these volcanoes release volatiles. Carbon/sulfur ratios are measured about weekly at the summit of Kilauea. A network of continuously monitoring stations using chemical sensors for individual gas species is under development. Another type of continuous monitoring, ambient air quality, is done in cooperation with the National Park Service at HAVO. Monitoring of ambient air quality provides information about the impact of volcanic emissions on air quality.

HVO collects accurate and timely ground-deformation data to monitor Hawaiian volcanoes. Data from tiltmeters are sampled every 10 minutes and provide the only real-time deformation monitor (HAVO). Continuous Global Positioning Survey (GPS) data are sampled every 30 seconds, but they currently download the data only once a day and calculate one-day average positions (HAVO). HVO conducts periodic (one or more times per year) leveling, GPS, EDM (electronic distance measurement) and dry tilt surveys (HAVO, HALE, PUHO, PUHE, KAHO). Each survey or data point can be compared with previously sampled data to determine accumulated ground deformation and to calculate strain rates or velocities. HVO is currently upgrading its deformation-monitoring program to emphasize real-time monitoring of Mauna Loa and Kilauea. This upgrade includes new installations of borehole dilatometers and tiltmeters, new installations of continuously recording GPS receivers, improved data logging and telemetry, and development of strain analysis and pattern recognition software.

HVO also produces geologic maps for the islands of Hawaii and Maui (Parks: HAVO, HALE, PUHE, PUHO, KAHO). Frank Trusdell maintains the flow field map of Mauna Loa. Christina Heliker maintains the map of the on-going eruption at Kilauea. Dave Sherrod is updating the map of HALE. Mapping projects use geologic mapping, isotopic dating (carbon-14, K-Ar, Ar^{40}-AR^{39}, He^3/He^4), paleomagnetic variation sampling, and chemical analyses to answer questions of timing, composition, periodicity, and extent of volcanism. Geophysical studies (gravity, magnetics) are elucidating the process of crater formation and distribution of downslope debris-avalanche deposits.

Projects by other groups include the ongoing, continuous thermal and infrasonic monitoring of Puu Oo vent starting in 2002. Andy Harris of the University of Hawaii is leading the monitoring project.

Lava tubes are hollow spaces beneath the surface of solidified lava flows. They are formed by the withdrawal of molten lava after the formation of the surface crusts. The HVO library has over 250 reports about lava tubes in the Hawaiian Islands. Most of these papers describe a survey or exploration of the tube system and are conducted through the Hawaii Speleological Survey. There are no long-term monitoring programs of old lava tubes and few short-term programs. Charles Cicciarella, from Louisiana Tech University, has been studying the temperature variations in volcanic steam caves since 2002. His program is expected to last three years. HVO monitors the active tube system of the current Kilauea eruption using geophysical techniques.

Mariana Islands

There are no long-term monitoring programs for volcanic activity in Guam or Saipan (Parks: WAPA, AMME). For the volcanoes north of Saipan, there are limited past and present monitoring efforts conducted by HVO and the CNMI EMO. These include geologic mapping, sampling of ash and lava flows for geochemical studies, EDM for deformation monitoring and seismic stations to gauge current activity.

American Samoa

There are no long-term monitoring programs for volcanic activity in American Samoa (Parks: NPSA).

SEISMICITY

Hawaiian Islands

The USGS (HVO and the National Strong Motion Program) and the Pacific Tsunami Warning Center (PTWC) of NOAA operate seismographic networks in the state of Hawaii. Each of these networks was established and operates to advance specific program goals. Although there is no formally established statewide entity for seismic monitoring, data are routinely exchanged and shared.

Seismic monitoring at HVO began in 1912. Since then, the seismographic network operated and maintained by HVO has expanded to over 60 stations on the Big Island. Data from remote stations are continuously telemetered in real-time to HVO. HVO's network coverage is most dense on Kilauea and Mauna Loa (Parks: HAVO). A sparser network of stations covers the other active volcanoes, Loihi and Hualalai (Parks: HAVO, PUHE, PUHO, KAHO). The most complete historical, empirical data on location of earthquake epicenters with attributes information for date, depth and magnitude for the other islands is be available from the USGS National Earthquake Information Center (NEIC) (Parks: HALE, KALA).

The Pacific Tsunami Warning Center (PTWC) in Ewa Beach, Hawaii, provides warnings for tsunami to most countries in the Pacific Basin as well as to Hawaii and all other US interests in the Pacific outside of Alaska and the US West Coast. The operational objective of the Tsunami Warning System (TWS) in the Pacific is to detect and locate major earthquakes in the Pacific region, to determine whether they have generated tsunami, and to provide timely and effective tsunami information and warnings to the population of the Pacific to minimize the hazards of tsunami, especially to human life and welfare. To achieve this objective, the TWS continuously monitors the seismic activity and ocean surface level of the Pacific Basin (Parks: HAVO, HALE, PUHE, PUHO, KAHO, KALA). The TWS is an international program requiring the participation of many seismic, tide, communication, and dissemination facilities operated by most of the nations bordering the Pacific Ocean. In addition, a tsunami hazard assessment model has been created by the NOAA Pacific Marine Environmental Laboratory (PMEL), which is being used to create new inundation zones. Tsunami modeling looks at seismic events, which can be local or teleseismic, bathymetry, storm, wind and rain conditions. PMEL models are best suited for teleseismic events while model developed by the UH SOEST Hawaii Institute of Geophysics may be more useful for localized earthquakes.

PUHE has a rapidly deployable camera for monitoring of tsunami. Whenever they receive a tsunami warning from the PTWC or civil defense, they place the camera on the monitoring post to try to film the event. A study of potential tsunami inundation zones for Molokai was completed in 1968 (Author unknown, 1968).

Mariana Islands

A seismic station operated by National Earthquake Information Center (NEIC) has been on Guam since 1985 and another before that since 1979. Many reports have been published about the August 1993 earthquake, which was remarkable for a relatively low amount of structural damage (and no loss of life) for such a high intensity (8.0) earthquake.

On Saipan, the EMO has a monitoring network of three stations – one in Saipan and two stations on two islands north of Saipan. EMO’s function is to monitor, record local earthquakes, keep logs and report significant earthquake events daily. Volcanologists, geologists, and other interested scientists have been furnished with such data.

The Pacific Tsunami Warning Center (PTWC) in Ewa Beach, Hawaii, provides warnings for teletsunami to all US interests in the Pacific. NOAA operates a moored buoy in Guam and also a water level gauge in Apra Harbor.

American Samoa

The closest seismic stations are located in Samoa and Tonga.

The Pacific Tsunami Warning Center (PTWC) in Ewa Beach, Hawaii, provides warnings for teletsunami to all US interests in the Pacific. In 1980, J.R. Houston published a paper on tsunami elevation prediction for American Samoa. The NOAA operates a tsunami early warning buoy in Pago Pago harbor.

EROSION/MASS WASTING

Hawaiian Islands

Relatively little information on erosion and sediment transport is available for Hawaiian watersheds that fall within PACN parks. Most of the information available was collected on the island of Oahu, which has no terrestrial parks. A sediment study has been done in the Pelekane watershed, above PUHE. Pelekane Bay, adjacent to PUHE, has had significant sedimentation impacts. While many of the data components are available for estimating which areas have highest risk for inland erosion, no known models have been created. NRCS interpretation of soils properties for highly erodable soils can be use as a rough indicator of landslides, whereas geologic properties together with slope could be used for rockslides. Several fishpond studies are being conducted in West Hawaii parks: 1) a breeding success study at Opaeula, conducted by Ducks Unlimited, 2) water quality and restoration (removal of algae) by NPS at Kaloko, 3) a nutrient composition study at Aimakapa by NPS, and 4) habitat restoration at Aimakapa, also by Ducks Unlimited.

Only landslides on Oahu have been studied. These have been measured, related to long-term landscape evolution, and may be applicable to the other islands.

Mariana Islands

The NPS is about to start a watershed-level project for the park: wildfire effects on erosion rates/effects of erosion on reefs. The erosion study will include erosion pins in and around WAPA. Sediment collection flumes are also installed just outside the park. The USGS conducted a stream sediment survey in southern Guam in 1983, but it is not clear if it was in or near WAPA units (Shade 1983). The USGS WRD maintains a gauge in the LaSaFua watershed on Guam that collects data on both flow and suspended sediment concentration. The WRD then combines these two measurements to calculate the total sediment load.

American Samoa

In 1981, J.M. Buchanan-Banks of the USGS wrote an open file report about landslides on Tutuila in 1979 (Buchanan-Banks 1981). In 1990, Donald White and Charles Stearns completed a landslide hazard mitigation study for Tutuila (White and Stearns 1990). The Coral Reef Initiative has a monitoring program for some American Samoa reefs, which includes criteria for sedimentation on the reefs. Otherwise, no terrestrial long-term monitoring programs have been initiated.

LITTORAL/MARINE

Hawaiian Islands

Detailed maps of long-term historic beach erosion have been created for portions of Oahu and Maui by UH SOEST Coastal Erosion Group (UH Coastal Geology Group – Prof. C. Fletcher). A coastal hazards atlas has been prepared for all of the main Hawaiian islands and is available on-line at: http://pubs.usgs.gov/imap/i2761/. Results of a USGS – UH beach monitoring program on Oahu and Maui is also available on-line at: http://geopubs.wr.usgs.gov/open-file/of01-308/. At PUHO, Rhodes conducted a detailed study of the oceanography – including currents, bathymetry, reefs and beaches – in 1969 (Rhodes 1969). Several studies have been published about the Honokohau harbor, next to KAHO, including one on the circulation of groundwater by Gallagher and Brent in 1980 (Gallagher 1980). Additionally at KAHO, the USGS is conducting a reef sedimentation project. At KALA, a study concerning the impacts of sand mining on dunes in the park was completed in 1988 (Canfield 1988). At HAVO, the production, erodability and longshore distribution of black sand beaches was studied by Floyd McCoy of Windward Community College in 1991.

Tide gauges located on the islands of Kauai, Oahu, Maui and Hawaii record fluctuations in local sea level and analysis of these records provides rates of long-term sea-level variation around the state. Results show that each island has its own rate of relative sea-level rise due to the local isostatic response. Should sea-level rise accelerate in the future, low-lying, low-relief, readily erodable and gentle slope coasts would be the most vulnerable to sea-level hazards. A study of RSL at PUHO was conducted in 1966 to find the rate of isostatic adjustment for Southern Hawaii (Apple and Macdonald 1966).

Lidar data of the west Kona parks was collected in 2000 by the Operational Airborne Lidar Survey (SHOALS) program http://shoals.sam.usace.army.mil/Pages/hawaii2000.htm. These data are being compared with older charts and maps to determine rates of long-term shoreline change with the Geologic Resource Evaluation underway by the USGS for the west Hawaii parks (Parks: PUHE, PUHO, KAHO).

Mariana Islands

In Guam, the EPA is starting a recreational beach-monitoring plan for coastal waters. In addition, they have a monitoring program for surface water. Studies about the effect of typhoons on shoreline change were conducted after typhoon Pamela in 1977 and typhoon Russ in 1991 (Ogg 1977, Richmond and Jaffe 1991). Several coral and beach inventories were conducted for all of Guam, such as one in 1976 (Randall and Eldredge 1976). Robert Dean conducted a field investigation of beach erosion at AMME in 1991, and other short-duration work has been done on the reefs and beaches of Saipan (Dean 1991, Eldredge and Randall 1980).

American Samoa

In 1994 and 1995, Cynthia Hunter conducted a beach monitoring and reef-mapping project (Hunter 1994, Maragos et. al. 1995). The American Samoa Coastal Management program has littoral-marine activity, but it is not clear if it is in the national park. The Coral Reef Initiative has a monitoring program for some American Samoa reefs designed to last from 2000-2005. The World Wildlife Fund (WWF) also has a coral reef monitoring program in progress to assess the impact of climate change. Involved in this program is a scheme to examine freshwater run-off and its impact on the reefs. It was scheduled to run from 2002-2004. Lance Smith, with the University of Hawaii, is studying coral reefs in Ofu Lagoon. He is comparing abiotic vs. biotic factors in the distribution and abundance of two coral reef species. Of interest are his measurements for water temperature, irradiance, water motion, salinity, sedimentation and disturbance. His study is expected to last from 2002 to 2005. Since 1999, NPSA has maintained several water temperature data loggers at near-surface sites in outer Vatia Bay, Tutuila, and also in the Ofu park unit.

SOIL

Hawaiian Islands

NRCS (Natural Resources Conservation Service) has soil maps of all Hawaiian islands based on research conducted in the 1950s and 1960s (Cline et. al. 1955, Foote et. al. 1972). The focus of existing soil survey mapping was on agricultural land use and was generalized for other areas. The southern and western portions of the island of Hawaii are currently being remapped in greater detail. This new mapping effort covers HAVO, and thus reflects a shift in the purpose to include conservation uses. NRCS has a soil temperature-monitoring program in HALE, started in 1975. In addition, Hawaii Civil Defense has funded research into soils mapping for seismic analysis. The University of Hawaii has a soil science department that studies Hawaiian soils extensively.

The Hawaii Ecosystem Project at Hawaii Volcanoes National Park, under the leadership of Peter Vitousek at Stanford University lab has many research projects on soil and nutrient cycling (Walker et. al. 1986, Matson et. al. 1987, Vitousek et. al. 1988, Vitousek et. al. 1992, Vitousek et. al. 1993, Vitousek et. al. 1995, Crews et. al. 1995, Holland et. al. 1995, Riley and Vitousek 1995, Raich et. al. 1996, Torn et. al. 1997, Townsend et. al. 1997, Martinelli et. al. 1999, Crews et. al. 2000, Treseder and Vitousek 2001). Soil studies in or near KAHO occurred in 1985 and in other years (Halbig et. al. 1985, Gardiner 1967, Barnard and Halbig 1985, Oshiro, date unknown). Soil studies in or near KALA occurred in 1951 and 1963 (Carlson 1951, Fernandez 1963). Francisco Perez of the University of Texas-Austin conducted a study concerning soil formation under Hawaiian silverswords in 1996 and 1998. At HAVO, P. Malaspina from the University of Hawaii analyzed paleosols in 1991 to learn about past climate conditions. Jene Michaud, from the University of Hawaii-Hilo, conducted a study to determine the rates and mechanisms of fluvial erosion in the ash covered areas of HAVO in 1999.

Mariana Islands

NRCS has published soil maps for Guam (Young 1988) and Saipan (Young 1989). There have been additional studies on Guam soils, mainly by the University of Guam and WERI. The University of Guam has a soil science lab and department in their college of natural sciences. As part of the NPS erosion study at WAPA, there is a soil quality and compaction survey occurring. McCracken and Ralph did extensive work on the soils of Saipan in the late 50s (Mccracken 1957, Mccracken 1953, Mccracken 1951).

Geological studies in Saipan include Cloud et al. (1958 and 1959). Cloud (1955) conducted beach and terrain analysis, and Eldredge and Randall (1980) studied Saipan's reefs and beaches.

Cloud (1959) analyzed submarine topography and shoal water ecology. Other studies include a subsurface soil investigation of Smiling Cove Marina (Geotesting 1987), topography, geology, and related water resources (Cole and Bridge 1953), general geological surveys (McCracken 1953 and Young 1989), limestones (Johnson 1957), and volcanic rocks (Schmidt 1954 and 1957). Siegrist (1989) evaluated a potential source of fine-aggregate in limestone bedrock deposits located in northeastern Saipan, following an earlier extensive geologic reconnaissance and sampling-testing program carried out in 1988. Soils were studied by McCracken (1957), and McCracken and Zarza (1958); the Natural Resources Conservation Service (1989) has published soil maps for Saipan. Paleontology studies include calcareous algae (Johnson 1957), discoaster (Bramlette 1957), radiolarian (Reidel 1957), foraminifera (Todd 1957 and Cole 1957), and echinoids (Cooke 1957).

American Samoa

NRCS has published soil maps for American Samoa (Nakamura 1984). There are no other monitoring programs for soils.

HYDROLOGY

Hawaiian Islands

The main office of the USGS-WRD Hawaii District is in Honolulu. The District operates a network of stations that collect information on streamflow, suspended sediment, lake and reservoir stage, groundwater level and salinity, rainfall, and evapotranspiration. The District also carries out interpretive studies on the quantity, quality, and dynamics of surface and groundwater (USGS WRD 2003). The USGS has estimated ground-water recharge and developed numerical ground-water flow models to quantify the hydrologic effects of groundwater withdrawals and to address the issue of long-term availability of groundwater in the Kona area on the island of Hawaii (Parks: KAHO, PUHO, PUHE; Shade 1995, Kauahikaua et. al. 1985). The USGS also maintains a streamflow gage at Oheo Gulch in HALE.

Baseline inventories and surveys of groundwater level, quality and salinity have occurred at PUHO in 1984, 1980, and 1999 (Author Unknown 1984, Bienfang 1980, National Park Service, Water Resources Division 1999). At PUHE, baseline inventories and surveys were conducted in 1968, 1969, 1971, 1977, 1986 and 1995 using a variety of techniques (Adams 1971, Adams et. al. 1969, Adams 1968, Adams 1969, Adams 1971, Halbig 1986, Neighbor Island Consultants 1974, Shade 1995). Wells were drilled in 1961 and 1963 in or near PUHE (Hawaii, Div Water and Land Devel 1961 and 1963). KAHO hydrology surveys were conducted in 1969, 1980, 1985 and 1999 (Cox et. al. 1969, Gallagher 1980, Kauahikaua et. al. 1985, Oki 1999, Oki et. al. 1999). There are three wells in KAHO and one upgradient. Water concerns of KAHO's anchialine ponds were studied in 1989 and 1998 (Jackson and Rosenlieb 1989, Rosenlieb et. al. 1998).

DLNR, the USGS and other organization have conducted basic studies of KALA. Some of these include: an inventory of the hydrology network for Molokai in 1970 (Hawaii Div. Water And Land Development 1970); groundwater studies in 1983, 1991, and 1992 (Kauahikaua 1983, M & E Pacific, Incorporated 1991, Mink and Lau 1992, Oki 1992); surface water studies in 1985, 1986, 1990 and 1995 (Takasaki 1985, Takasaki 1986, Smith 1990, Anthony 1995, Diaz et. al. 1995); and park specific studies in 1982 and 1996 (Takasaki 1982, National Park Service 1996).

Many of these reports focus on the Waikolu and Waihanau valleys. The Waikolu stream is the source of a transbasin water diversion system, operated since 1961, which sends water to western Molokai. KALA is a member of the recently formed East Molokai Watershed Partnership. This coalition is composed of a group of landowners, government agencies and non-government organizations whose purpose is to cooperate in the management of natural ecosystems to preserve native ecosystems and conserve watersheds. A project was identified in Kalaupapa's Resource Management Plan to compare hydrologic and biologic attributes of the Waikolu Stream watershed with hydrologic and biologic attributes of the nearby Pelekunu Stream watershed. Studies have shown that the Waikolu diversions have caused adverse effects on instream biotic resources while Pelekunu Stream has remained in a more natural state (Brasher 1997).

FEMA has initiated a flood map modernization effort, which calls for acquiring LIDAR imagery. Once the imagery is collected and elevations derived, FEMA will derive new flood map products using historical/empirical information combined with modeling.

Mariana Islands

USGS-WRD Hawaii District has a field office in Saipan. The District operates a network of stations that collect information on streamflow, suspended sediment, lake and reservoir stage, groundwater level and salinity, rainfall, and evapotranspiration. The District also carries out interpretive studies on the quantity, quality, and dynamics of surface and groundwater. They have activities in both Guam and Saipan (Hoffmann 1995, USGS WRD 2003).
The CNMI Division of Environmental Quality (DEQ) was created to protect groundwater resources through the permitting of underground and surface alteration activities. DEQ laboratory staff conducts weekly monitoring of groundwater wells, tap water, commercially sold drinking water and marine water. They are mainly concerned with water quality, but could make a good partnering agency.

The EPA is part of an effort to monitor and clean up the Puerto Rico Dump on Saipan, which is on a 220-acre site that juts into the Saipan Lagoon. The landfill is just north of the AMME’s boundary. The Army Corps of Engineers maintains and monitors wells near the park. The Guam EPA is also conducting several projects on Guam, mainly focused in the karst area of Northern Guam.

The Water and Environmental Research Institute (WERI) of the Western Pacific was established as a research unit of the University of Guam in May 1975. The role of the Institute is to provide water and energy resources information by conducting basic and applied research in an interdisciplinary environment, training students, and disseminating research results. It has several projects in Guam and Saipan. Data is available on their web site, including well water level, surface water flow and water quality. The bulk of the hydrologic work on Guam is conducted in the northern karst area. However, the park sits in the southern physiographic region. Surveys conducted near the parks include a study in 1994 on the runoff in Central Guam (Nakama 1994).

A hydrological study of the wetland in AMME has been funded for 2005 by the National Park Service Water Resources Division. The U.S. Geological Survey Water Resources Division in Saipan will conduct the work through an interagency agreement. In addition, a biological study of the Puerto Rico mudflat has been funded by American Memorial/ War in the Pacific for 2005

Six stations within American Memorial Park were used for a wetland hydrology assessment in 1990 (Wagner 1990).

Hydrological studies include Davis (1958), Tenorio Engineers (1973), and van der Brug (1985).

American Samoa

The USGS-WRD Hawaii District operates a network of stations on Tutuila that collect information on streamflow, groundwater level and salinity, rainfall, and evapotranspiration (USGS WRD 2003). The District also carries out interpretive studies on the quantity, quality, and dynamics of surface and groundwater. They compile annual summaries of groundwater data and recently completed a hydrologic atlas of Tutuila.

There are several studies on stream morphology and stream flow as well as groundwater quality, but these were not turned into long-term monitoring programs (Courts 1983, Eyre 1994, Matsuoka 1978, Wong 1995). More recent efforts by ASEPA have established monitoring stations in several Tutuila streams.The American Samoa Power Authority (ASPA) does limited monitoring of the hydrology of American Samoa, mainly water quality. They would be a good organization to try to partner with. American Samoa Environmental Protection Agency (ASEPA) is also another organization that works with hydrology in American Samoa (Eyre 1994), largely in partnership with the USGS.

SUMMARY

Table 2. Summary of park monitoring efforts and geologic concerns at PACN Parks

Ecological importance, degree of human influence, management significance and current monitoring efforts of selected geoindicators at PACN parks		Littoral-Marine				Groundwater				Surface water					
		Dune formation and reactivation	Coral chemistry and growth pattern	Relative sea level	Shoreline position	Groundwater chem in the unsat. zone	Groundwater level	Groundwater quality	Karst activity (incl pseudokarst)	Lake (anchialine) levels and salinity	Surface water quality	Stream channel morphology	Streamflow	Stream seds storage and load	Wetland extent, struct and hydrol
ALKA	Ecological importance	L	H	H	H	H	H	H	L	L	L	M	L	M	H
	Human influence	L	H	L	H	H	H	H	H	H	H	H	H	H	H
	Management significance	?	?	?	?	?	?	?	?	?	?	?	?	?	?
	Currently being monitored?	No	No	Yes	No	?	?	No	No	No	?	No	No	No	No
AMME	Ecological importance	L	H	H	H	H	H	H	H	?	H	H	H	H	H
	Human influence	L	H	L	H	H	H	H	L	?	H	H	H	H	H
	Management significance	L	H	L	L	L	L	H	L	L	H	L	L	L	H
	Currently being monitored?	No	No	No	No	?	?	?	No	No	?	No	?	Yes	Yes
HALE	Ecological importance	L	M	M	M	H	H	H	L	M	H	H	H	H	M
	Human influence	L	L	L	L	L	L	M	M	L	L	L	L	L	L
	Management significance	L	L	L	L	L	L	L	H	H	H	H	H	H	L
	Currently being monitored?	No	No	No	No	No	No	No	No	No	?	Yes	Yes	No	No
HAVO	Ecological importance	L	H	M	M	H	H	H	L	L	H	L	M	M	H
	Human influence	L	L	L	L	L	L	M	H	L	L	L	L	L	L
	Management significance	L	H	L	M	L	L	L	M	M	H	L	L	L	H
	Currently being monitored?	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No
KAHO	Ecological importance	L	H	H	H	H	H	H	L	L	H	M	M	H	H
	Human influence	L	H	L	M	H	H	H	?	H	H	H	H	H	H
	Management significance	L	M	H	H	H	H	H	L	M	H	M	M	M	H
	Currently being monitored?	No	No	Yes	No	No	No	Yes	No	?	Yes	No	No	No	?
KALA	Ecological importance	L	M	M	M	H	H	H	L	L	H	M	H	H	M
	Human influence	L	L	L	L	M	M	M	?	M	L	H	H	M	L
	Management significance	L	H	L	L	L	M	M	L	L	L	H	H	M	L
	Currently being monitored?	No	No	No	No	No	No	No	No	No	No	No	No	?	No
NPSA	Ecological importance	L	H	H	H	H	H	H	L	L	H	H	H	H	H
	Human influence	L	H	L	H	H	H	H	?	?	H	H	H	H	H
	Management significance	L	H	M	L	L	L	M	L	L	H	H	H	H	L
	Currently being monitored?	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No
PUHE	Ecological importance	L	H	H	H	H	H	H	L	L	L	M	M	H	L
	Human influence	L	H	L	H	H	H	H	?	-	H	H	H	H	H
	Management significance	L	H	L	H	L	L	L	L	L	L	L	L	H	L
	Currently being monitored?	No	No	No	No	No	No	?	No	No	?	No	No	No	No
PUHO	Ecological importance	L	H	H	H	H	H	H	L	L	H	L	L	L	H
	Human influence	L	H	L	M	H	H	H	?	M	H	H	H	H	H
	Management significance	L	H	H	H	H	H	H	L	H	H	L	L	L	H
	Currently being monitored?	No	No	Yes	No	No	?	?	No	No	?	No	No	No	?
USAR	Ecological importance	L	H	M	M	L	L	M	L	L	H	L	L	M	L
	Human influence	-	H	L	H	H	H	H	-	-	H	H	H	H	H
	Management significance	?	?	?	?	?	?	?	?	?	?	?	?	?	?
	Currently being monitored?	No	No	Yes	No	?	?	?	No	No	?	No	Yes	?	?
WAPA	Ecological importance	L	H	H	H	H	H	H	H	L	M	M	M	H	M
	Human influence	?	H	L	H	H	H	H	H	?	H	H	H	H	H
	Management significance	L	H	M	M	L	L	L	M	L	L	L	L	H	L
	Currently being monitored?	No	?	Yes	No	No	No	?	No	No	?	No	?	Yes	No

Ecological importance, degree of human influence, management significance and current monitoring efforts of selected geoindicators at PACN parks		Volcanic			Arid and Semi-Arid		Other (multiple environment)				
		Volcanic unrest	Seis-micity	Sub-surface temp regime	Desert biotic crusts and pave-ments	Wind erosion	Slope failure (land-slides)	Soil and seds erosion	Soil quality	Seds sequence and comp-osition	Surface displacement (subs, uplift)
ALKA	Ecological importance	H	H	L	M	M	H	H	H	L	M
	Human influence	L	L	L	H	H	H	H	H	L	M
	Management significance	?	?	?	?	?	?	?	?	?	?
	Currently being monitored?	Yes	Yes	No	No	No	No	No	No	No	No
AMME	Ecological importance	L	M	L	L	L	M	H	H	L	L
	Human influence	L	L	L	L	M	H	H	H	M	L
	Management significance	L	L	L	L	L	M	H	L	L	
	Currently being monitored?	No	Yes	No	No	No	No	Yes	No	No	No
HALE	Ecological importance	H	H	L	L	L	H	H	H	L	L
	Human influence	L	L	L	M	M	L	M	L	L	L
	Management significance	M	M	M	L	L	L	L	L	L	L
	Currently being monitored?	Yes	Yes	No	No	No	No	No	No	No	No
HAVO	Ecological importance	H	H	H	H	M	H	H	H	L	H
	Human influence	L	L	L	M	M	L	M	L	L	L
	Management significance	H	H	H	L	L	L	L	L	L	L
	Currently being monitored?	Yes	Yes	Yes	No	No	No	No	No	No	Yes
KAHO	Ecological importance	H	H	L	L	L	L	M	H	L	L
	Human influence	L	L	L	L	L	L	H	M	M	L
	Management significance	M	L	L	L	L	L	H	L	L	H
	Currently being monitored?	Yes	Yes	No	No	No	No	No	No	No	No
KALA	Ecological importance	L	H	L	L	L	H	H	H	L	L
	Human influence	L	L	L	L	L	L	L	M	H	L
	Management significance	L	M	L	L	L	H	L	L	L	L
	Currently being monitored?	No	Yes	No	No	No	No	?	No	No	No
NPSA	Ecological importance	M	M	L	L	L	H	H	H	L	L
	Human influence	L	L	L	L	L	H	H	H	H	L
	Management significance	L	L	L	L	L	L	M	L	L	L
	Currently being monitored?	No	Yes	No	No	No	No	No	No	No	No
PUHE	Ecological importance	L	H	L	L	H	L	H	H	L	L
	Human influence	L	L	L	H	H	M	H	H	H	L
	Management significance	L	L	L	H	H	L	H	L	L	L
	Currently being monitored?	Yes	Yes	No	No	No	No	?	No	No	No
PUHO	Ecological importance	H	H	L	L	L	L	H	H	L	L
	Human influence	L	L	L	L	L	L	H	M	M	L
	Management significance	L	L	L	L	L	L	M	L	L	L
	Currently being monitored?	Yes	Yes	No	No	No	No	No	No	No	No
USAR	Ecological importance	L	M	L	L	L	L	L	L	L	M
	Human influence	L	L	L	-	-	-	-	-	L	L
	Management significance	?	?	?	?	?	?	?	?	?	?
	Currently being monitored?	No	Yes	No	No	No	No	No	No	No	No
WAPA	Ecological importance	L	M	L	L	L	M	H	H	L	L
	Human influence	L	L	L	L	L	H	H	H	M	L
	Management significance	L	L	L	L	L	M	H	L	L	L
	Currently being monitored?	No	Yes	No	No	No	No	Yes	No	No	No

Ecological importance	Human influence	Management significance	Currently being monitored?
H = High importance	H = Highly influenced by	H = High significance	Yes
M = Moderate importance	M = Moderately influenced by	M = Moderate significance	No
L = Low importance	L = Little influence by	L = Low significance	?

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In Memoriam
Eric Rutherford
August 8, 1974 - November 12, 2003

Eric Rutherford volunteered for the Geology Group at the Hawaiian Volcano Observatory from September to December 2002. He returned in January 2003 to work with Frank Trusdell for the National Park Service, compiling geologic data about National Parks in the Pacific Islands for the NPS Inventory and Monitoring Program. Eric left Hawaii in mid-August to begin graduate school at the University of Texas in Austin. He was diagnosed with cancer on October 1, 2003, and passed away on November 12, 2003.
(USGS Hawaiian Volcano Observatory website)

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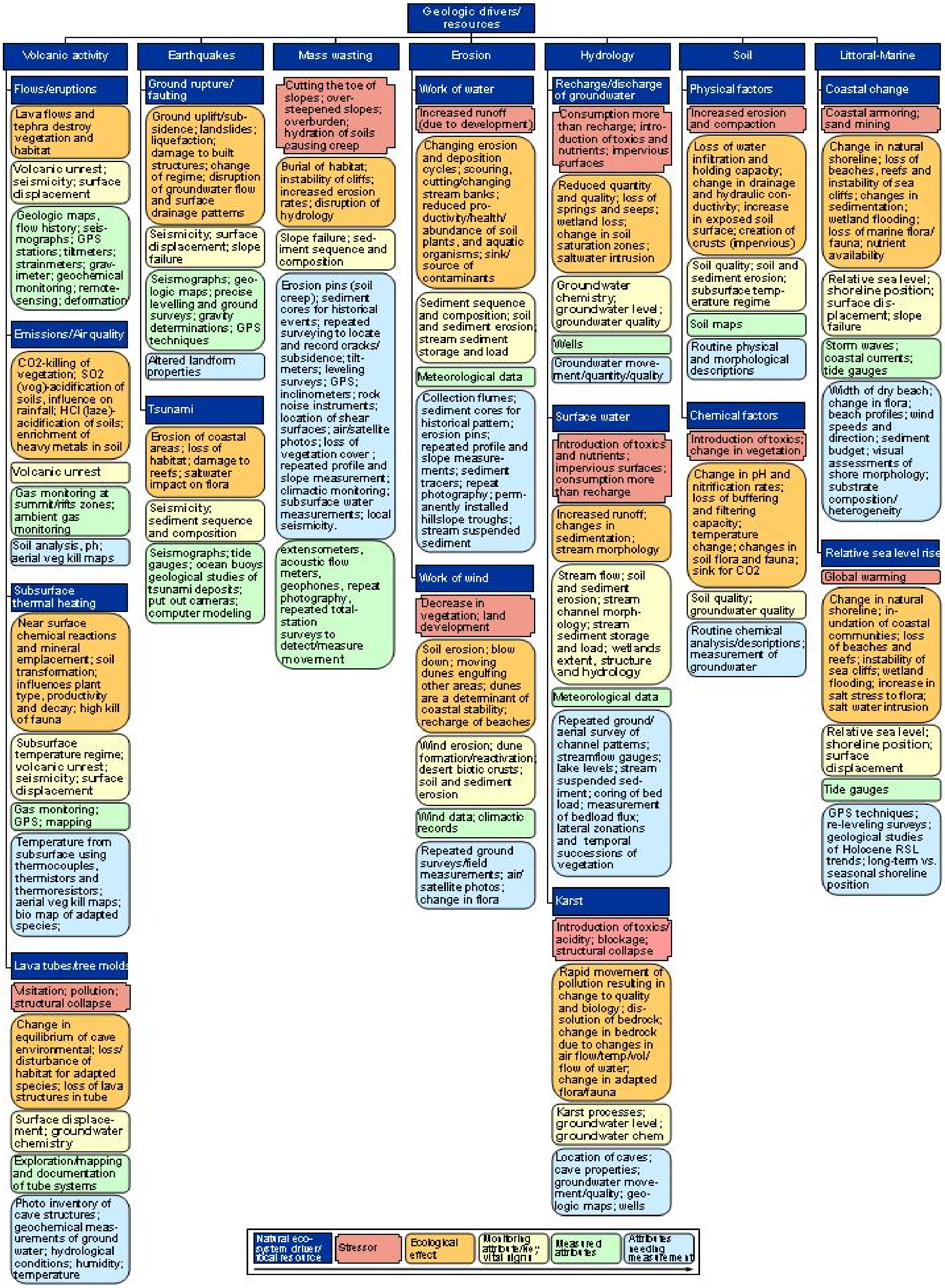
APPENDIX B: CONCEPTUAL MODEL



APPENDIX C: LIST OF GEOINDICATORS

See: (http://www.gcrio.org/geo/toc.html) The following is a brief description of the significance of each geoindicator:

A.1. *Frozen ground activity: Permafrost influences natural and managed ecosystems, including forests, grasslands and rangelands, mountains and wetlands, and their hydrological systems. It is an agent of environmental change that affects ecosystems and human settlements. Permafrost may enhance further climate change by the release of carbon and other greenhouse gases during thawing. It is estimated that nearly 1/4 of the world's terrestrial carbon is tied up in dead organic mater in the active layer and in permafrost: long-term climate warming would facilitate decomposition and drying, releasing huge quantities of methane and CO2 [see wetlands extent, structure and hydrology]. Permafrost can result in serious and costly disruptions from ground subsidence, slope failure, icings, and other cryogenic processes.

A.2. *Desert biotic crusts and pavements: Desert surface crusts are important because they protect the underlying fine material from wind erosion.

A.3. *Dune formation and reactivation: Moving dunes may engulf houses, fields, settlements and transportation corridors. They also provide a good index of changes in aridity. Coastal dunes are important determinants of coastal stability, supplying, storing and receiving sand blown from adjacent beaches. Dunes play an important role in many ecosystems (boreal, semi-arid, desert, coastal) by providing morphological and hydrological controls on biological gradients.

A.4. *Wind erosion: Changes in wind-shaped surface morphology and vegetation cover that accompany desertification, drought, and aridification are important gauges of environmental change in arid lands. Wind erosion also affects arid and semi-arid regions, by removing topsoil, seeds and nutrients.

A.5. Dust storm magnitude, duration, and frequency: Local, regional and global weather patterns can be strongly influenced by accumulations of dust in the atmosphere. Dust storms remove large quantities of surface sediments and topsoil with nutrients and seeds. Wind-borne dust, especially where the grain size is less than 10 µm, and salts are known hazards to human health. Dust storms are also an important source of nutrients for soils in desert margin areas.

A.6. Coral chemistry and growth patterns: The combination of abundant geochemical tracers, sub-annual time resolution, near-perfect dating capacity, and applicability to both current and past climatic changes establishes corals as one of the richest natural environmental recorders and archives. A 30 cm-diameter coral colony growing at an average rate of 1 cm/yr will provide 20-25 years of baseline data, whereas massive colonies 3-6 m high may provide historical data for extensive tracts of tropical ocean, such as are not otherwise available.

A.7. Relative sea level: Changes in RSL may alter the position and morphology of coastlines, causing coastal flooding, waterlogging of soils and a loss or gain of land. They may also create or destroy coastal wetlands and salt marshes, inundate coastal settlements, and induce salt-water intrusion into aquifers, leading to salinization of groundwater. Coastal ecosystems are affected, for example, by increased salt stress on plants. A changing RSL may also have profound effects on coastal structures and communities. Low-lying coastal and island parks are particularly susceptible to sea-level rise. It is estimated that 70% of the world's sandy beaches are affected by coastal erosion induced by RSL rise.

A.8. *<u>Shoreline position</u>: Changes in the position of the shoreline affect transportation routes, coastal installations, communities, and ecosystems. The effects of shoreline erosion on coastal communities and structures can be drastic and costly. It is of paramount importance for coastal parks to know if local shorelines are advancing, retreating or stable. Rates of recession as high as 5-10 m/yr have been measured in many places around the world, and much higher rates have been recorded locally. Coastal erosion in the USA alone is estimated to cost $700 million annually.

A.9. <u>Groundwater chemistry in the unsaturated zone</u>: Changes in recharge rates are physical attributes that have a direct relationship to water resource availability in terms of water chemistry. The unsaturated zone may store and transmit pollutants, the release of which may have a sudden adverse impact on groundwater quality.

A.10. <u>Groundwater level</u>: Groundwater is the major source of water in many regions. In the USA, more than half the drinking water comes from the subsurface: in arid regions it is generally the only source of water. The availability of clean water is of fundamental importance to the sustainability of life. It is essential to know how long the resource will last and to determine the present recharge: groundwater mining is a terminal condition.

A.11. <u>Groundwater quality</u>: Groundwater is important for human consumption, and changes in quality can have serious consequences. It is also important for the support of habitat and for maintaining the quality of baseflow to rivers. The chemical composition of groundwater is a measure of its suitability as a source of water for human and animal consumption, irrigation, and for industrial and other purposes. It also influences ecosystem health and function. It is important to detect change and early warnings of change both in natural systems and resulting from pollution.

A.12. *<u>Karst activity</u>: It is estimated that karst landscapes occupy up to 10% of the Earth's land surface, and that as much as a quarter of the world's population is supplied by karst water. The karst system is sensitive to many environmental factors. The presence and growth of caves may cause short-term problems, including bedrock collapse, disparities in well yields, poor groundwater quality because of lack of filtering action, and instability of overlying soils.

A.13. <u>Lake levels and salinity</u>: The history of fluctuations in lake levels provides a detailed record of climate changes on a scale of ten to a million years. Lakes can also be valuable indicators of near-surface groundwater conditions.

A.14. <u>Surface water quality</u>: Clean water is essential to human survival as well as to aquatic life. Pathogens such as bacteria, viruses and parasites can make polluted waters among the world's most dangerous environmental problems. Water quality data are essential for the implementation of responsible water quality management, for characterizing and remediating contamination, and for the protection of the health of humans and aquatic organisms.

A.15. *<u>Stream channel morphology</u>: Channel dimensions reflect magnitude of water and sediment discharges. An understanding of stream morphology can help delineate environmental changes of many kinds. Changes in stream pattern, which can be very rapid in arid and semi-arid areas, can limit land use and alter habitat, such as on islands in braided streams and meander plains, or along banks undergoing erosion.

A.16. <u>Streamflow</u>: Streamflow directly reflects climatic variation. Changes in streams and streamflow are indicators of changes in basin dynamics and land and water use, for example stream water diversion or groundwater pumpage for agricultural uses or groundwater.

A.17. *Stream sediment storage and load: Sediment load determines channel shape and pattern [see stream channel morphology]. Changes in sediment yield reflect changes in basin condition, including climate, soils, erosion rates, vegetation, topography and land use. Fluctuations in sediment discharge affect many terrestrial and coastal processes, including ecosystem responses, because nutrients are transported together with the sediment load. Stream deposits also represent huge potential sinks for, and sources of, contaminants.

A.18. Wetlands extent, structure and hydrology: Wetlands are areas of high biological productivity and diversity. They provide important sites for wildlife habitat and human recreation. Wetlands mediate large and small-scale environmental processes by altering downstream catchments. Wetlands can affect local hydrology by acting as a filter, sequestering and storing heavy metals and other pollutants, such as Hg, and serving as flood buffers and, in coastal zones, as storm defenses and erosion controls.

A.19. *Volcanic unrest: Natural hazards associated with eruptions of the world's 550 or so historically active volcanoes pose a significant threat to about 10% of the world's population, especially in densely-populated circum-Pacific regions. By the year 2000, more than half a billion people will be at risk.

A.20. *Seismicity: Earthquakes constitute one of the greatest natural hazards to human society. Between 1960 and 1990 earthquakes killed about 439,000 people worldwide and caused an overall economic loss of some $ 65 billion. Surface effects include uplift or subsidence, surface faulting, landslides and debris flows, liquefaction, ground shaking, and tsunami (‘tidal’ waves caused by undersea tremors). Damage to buildings, roads, sewers, gas and water lines, power and telephone systems, and other built structures commonly occur.

A.21. *Slope failure (landslides): Annual property damage from landslides worldwide is estimated in the tens of billions of dollars, with more than $1.5 billion in annual losses in the USA alone. There are innumerable small to medium-size slope failures that cumulatively impose costs to society as great as or greater than the large infrequent catastrophic landslides that draw so much attention. Landslides can alter habitat and impact resources down slope and add sediment to waterways.

A.22. *Soil and sediment erosion: Soil erosion is an important social and economic problem and an essential factor in assessing ecosystem health and function. Estimates of erosion are essential to issues of land and water management, including sediment transport and storage in lowlands, reservoirs, estuaries, and irrigation and hydropower systems. In the USA, soil has recently been eroded at about 17 times the rate at which it forms.

A.23. *Soil quality: As one of Earth's most vital ecosystems, soil is essential for the continued existence of life on the planet. As sources, stores, and transformers of plant nutrients, soils have a major influence on terrestrial ecosystems. Soils continuously recycle plant and animal remains, and they are major support systems for human life, determining the agricultural production capacity of the land. Soils buffer and filter pollutants, they store moisture and nutrients, and they are important sources and sinks for CO_2, methane and nitrous oxides. Soils are a key system for the hydrological cycle [see groundwater chemistry in the unsaturated zone]. Soils also provide an archive of past climatic conditions and human influences.

A.24. *Subsurface temperature regime: The thermal regime of soils and bedrocks exercises an important control on the soil ecosystem, on near-surface chemical reactions (e.g. involving groundwater), and on the ability of these materials to sequester or release greenhouse gases. It may affect the type, productivity and decay of plants, the availability and retention of water, the rate of nutrient cycling, and the activities of soil microfauna. It is also of major importance as an archive of climate change, indicating changes in surface temperature over periods of up to 2-3 centuries, for example in regions without a record of past surface temperatures. In permafrost, the ground temperature controls the mechanical properties of the soils, especially during the freeze-thaw transition in the active layer.

A.25. *Sediment sequence and composition: The chemical, physical and biological character of aquatic sediments can provide a finely resolvable record of environmental change, in which natural events may be clearly distinguishable from human inputs.

A.26. *Surface displacement: Most surface displacements have but minor effects on landscapes and ecosystems. However, there are exceptions, such as where drainage channels are suddenly displaced by faults, or where seismically induced uplift raises intertidal ecosystems above sea-level. Moreover, extraction of fluids can induce land subsidence and cause flooding, especially of coastal parklands near sea-level. Subsidence damages buildings, foundations and other built structures.

** denotes geoindicators that are particularly relevant to PACN parks*

APPENDIX D: IMPORTANT SOURCES

This report borrows heavily from work already completed, including:

Izuka, Scot, 2004, Personal Communication and review of earlier drafts of this document

Low, Rod, and Yamashita, Eric. 2003. Chapter 0: Physical Environment and Natural Hazards.

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